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USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l18 and l1	2	L19
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USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l16 and display	11	L17
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USPT,PGPB,JPAB,EPAB,DWPI,TDBD	(fault isolation manual) or FIM	951	L15
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l7 and display	37	L14
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l8 and display	10	L13
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l9 and display	26	L12
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l10 and display	7	L11
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l6 and l1	16	L10
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l6 and l4	28	L9
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l6 and l2	33	L8
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l6 and l3	173	L7
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	aircraft or airplane or aerodyne	170566	L6
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	l1 and l2 and l3 and l4	0	L5
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	EICAS	36	L4
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	CMC	16579	L3
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	FIM	950	L2
USPT,PGPB,JPAB,EPAB,DWPI,TDBD	(flight deck effect) or FDE	132	L1

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L11: Entry 5 of 7 File: USPT Nov 3, 1992

DOCUMENT-IDENTIFIER: US 5161158 A
TITLE: Failure analysis system

BSPR:
In avionics systems, failure propagation and fault isolation are two important aspects of system behavior. Failure propagation refers to the effect on overall system performance of a system component failure. Fault isolation refers to the process of locating a failed system component. A failed component normally creates a failure indication on the flight deck of an aircraft, commonly referred to as a flight deck effect. The flight deck effect is thus the clue to the faulty component. These same types of failure analyses must be performed in other electronics systems that share certain common characteristics with avionics systems.

BSPR:
During a fault isolation analysis, the failure response, i.e., flight deck effect, is traced "backwards" to a source LRU that may have caused the flight deck effect to be generated. During the analysis, the aircraft operating configuration at the time the flight deck effect was generated must be taken into account when the system analyst refers to the system documentation. As with the failure propagation simulation, manually isolating faults may be a time-consuming and difficult process.

BSPR:
One reason for the signal source redundancies in avionics systems is the high level of functional availability required in aircraft operation. As an example of the use of signal source redundancy, important LRU signals are usually generated by more than one source, e.g., a left and right source. The LRUs that receive multiple signals must be provided with a way of selecting an initial signal source, determining when the signal source has failed, and selecting an alternate source. In instances where there are more than two signal sources, e.g., left, center, and right sources, a hierarchy of source selection is required. Source selection may be automatically controlled by hardware or software that is a part of an LRU or the avionics system. Additionally, for certain subsystems, the source selection is performed manually by the flight crew in response to a flight deck effect. In order to comprehensively test avionics system behavior, it is necessary to test the system response in a variety of operating configurations that are each defined by a set of initial source selections.

BSPR:
An LRU's behavior may be highly dependent upon system mode and external conditions. The system mode describes the aircraft's flight trajectory. The trajectory includes take-off, climb, cruise, descend, land, and go-around modes. Each mode is further described by pitch, roll, and throttle, i.e. power, characteristics. External conditions include altitude, speed, etc. Thus, besides having certain behavioral characteristics based on input source selection, an LRU's behavior may also be contingent on the system mode and/or external conditions.

DEPR:
An avionics system's operating configurations are generally defined by the knowledge base 12. Taken as a whole, the knowledge base describes a range of avionics system physical configurations and behavioral characteristic for a single aircraft. To identify a specific operating configuration for a simulation, simulation condition parameters are received by the user interface 14 from a system analyst or other source. The system analyst also identifies the type of

simulation to be performed, i.e., failure propagation or fault isolation, and selects the component failure or failure response to be analyzed via the user interface.

DEPR:
During the simulation of a failure effect propagation, the failure analysis engine 16 simulates the propagation of the initial failure's effect through an avionics system described by the knowledge base and the simulation condition parameters. The result is a list of failures that would result from the initial failure. Additionally, a list of flight deck effects, which are the failure or warning indications that are presented to the flight crew via the flight deck, is generated. During a fault isolation analysis, the failure analysis engine processes the selected failure response "backwards" through the knowledge base to simulate a fault isolation analysis in an avionics system described by the knowledge base and the simulation condition parameters. The procedure results in a list of possible failure sources, i.e., faulty components, the failure of which may have caused the flight deck effect to be generated. Because the knowledge base along with the simulation condition parameters represents a specific avionics system operating configuration, by altering the knowledge base and/or the simulation condition parameters, a different avionics system operating configuration is defined and can be analyzed.

DEPR:
In one embodiment, source selection, system mode, and external condition parameters make up the simulation condition parameters. The source selection parameters describe the initial LRU input source selection. For some LRUs, data source selection is performed manually by the setting of flight deck source selection switches. A flight deck source selection switch drives a hardware relay that is internal or external to an LRU. Changing the position of a flight deck source selection switch actually changes the path along which a signal travels. System mode parameters describe the aircraft's flight trajectory. System modes include: take-off, climb, cruise, descend, land, and go-around. In each mode, the flight trajectory is further described by pitch, roll and autothrottle, i.e., power, parameters. The external condition parameters include speed and altitude.

DEPR:
With reference to FIG. 2, the set-up module provides the system analyst with a screen through which to enter the values or states of the simulation condition parameters. In one actual embodiment, the system analyst enters: aircraft identification, Instrument Select (IS) switch position, Flight Management Computer (FMC) master switch position, and Flight Director (F/D) switch position, autoflight (system) mode selections, and external conditions values. The switch positions dictate the data sources for specific LRUs at the beginning of the simulation. The autoflight mode selections dictate the system mode for the simulation. In one embodiment, if a parameter value is not entered by the system analyst, the user interface sets the parameter to a default value.

DEPR:
With reference to FIGS. 3A and 3B, in one actual embodiment the user interface formats the LRU failure rules and the source selection rules into readable logical statements. The logical statements provide further explanation of how the rules are applied. The data extracted from the rules appear in bold type in the logical statements. In order to obtain the display, the system analyst uses the user interface to select either an LRU failure rule or source selection rule, and then to identify the LRU name, LRU location, and unique rule number. The user interface extracts the data from the knowledge base. If an LRU failure rule is selected, the user interface extracts the LRU subrule identified by the unique rule number and then extracts the text and results for the response by matching the response code in the LRU subrule to the response code in the result data.

DEPR:
Before describing the failure effect propagation simulation of the failure analysis expert system, a diagrammatical example of the propagation of an LRU failure's effect is presented. With reference to FIG. 4, a partial avionics system is illustrated, specifically a portion of the left side of the system. Thus, all of the LRUs illustrated have a right or some other counterpart system (not shown). An Air Data Computer-Left (ADC-L) failure's effect, given the simulation condition parameters illustrated in FIG. 2, results in at least three other LRUs experiencing some level of failure and causes at least two flight deck

effects to be generated.

DEPR:
The expert system records those LRUs and signals that would fail during the propagation as the failure history, displays the failure responses at each level of propagation, and displays the flight deck effects that result from the failure(s). The failure history from each failure simulation is used when multiple failures are simulated. To analyze multiple failures, each subsequent failure is propagated through the knowledge base in accordance with the simulation conditions and the prior failure history.

DEPR:
Another important aspect of avionics system testing is fault isolation. Fault isolation is essentially the reverse of a failure effect propagation since a set of possible failure sources are generated from a set of flight deck effects. Generally, an LRU fault results in one or more flight deck effects depending on the severity of the fault and its potential impact on flight safety. Flight deck effects include messages shown on the Engine Indicating and Crew Alerting System (EICAS) displays and Control Display Units (CDUs), symbols or erroneous data on the Primary Flight and Navigation Displays (PFDs and NDs), caution and warning lights, and alarms. It is feasible that a number of discrete faults will result in the generation of the same flight deck effect(s). Thus, the flight or maintenance crews do not always know the source of a given flight deck effect. The failure analysis expert system includes a recursive backtracking procedure for isolating the source(s) of a flight deck effect. The fault isolation analysis can be used by maintenance personnel to generate a set of possible fault sources from a flight deck effect(s) and a set of simulation condition parameters.

DEPR:
One benefit of the present fault isolation analysis is that an actual operating configuration can be recorded when a flight deck effect occurs in-flight and then the simulation condition parameters can be set equal to the actual conditions. The combination of the knowledge base with the simulation condition parameters describes an avionics system configuration equivalent to the one in which the flight deck effect actually occurred. In this manner, the possible sources for the flight deck effect(s) are narrowed to those that are relevant to the actual operating configuration.

DEPR:
The fault isolation analysis follows each possible fault source, one source at a time, from the flight deck effect to the fault source. The analysis continues until all possible fault sources are identified. In order to identify each of the LRUs that might have caused the flight deck effect, i.e., initial response, to be generated, the subrules are considered to identify those subrules that describe the generation of the initial response. A relevant subrule identifies a destination LRU, which, if failed, could have caused the response to be generated. The subrule is only analyzed if the simulation condition code in the subrule matches the simulation condition parameters describing the operating configuration. If a subrule is relevant, the result data is referenced to identify those responses that would have caused an input signal to the destination LRU to fail. Each identified response, in turn, is then analyzed as described above until a source LRU is found. The recursion continues until all relevant subrules and all possible failed signals are analyzed.

DEPR:
With reference to FIG. 6, the first portion of the fault isolation analysis is similar to the failure propagation simulation. At block 70, the system analyst utilizes the set-up module screen to establish the simulation condition parameters. The system analyst selects the flight deck effect, i.e., initial response, via the failure analysis module. Alternatively, the simulation condition parameters and/or flight deck effect may be initialized according to recorded in-flight data that describes the actual flight operating configuration during which a flight deck effect occurred. Such data might be read from a tape or other data storage device. At block 72, the backtrack recursive process begins against the initial response.

DEPR:
Once a possible source of the initial response is identified as block 82, the destination LRU is displayed or stored. At block 86, the procedure considers

whether all of the subrules that match the destination LRU and the simulation condition parameters have been matched. If they have not been, the procedure returns one level up in the recursion process to block 74. If all of the subrules relevant to a destination LRU have been considered, at block 88, the procedure determines whether all of the significant signals in the data ID list have been analyzed. If the data ID list is not empty, then, at block 76, the next significant signal is extracted from the list and the process of matching the next result data by the condition value is performed. Once all of the signals in the data ID list have been completely backtracked, the procedure ends. Since the procedure is recursive, it steps one level up in the recursion to block 74 and continues. The process continues until each possible source is identified. As noted, as the possible sources are identified, they are displayed or written to a file. The system analyst may then use the list of possible faults as a starting point for further testing of the avionics system in order to identify the true or most likely source(s) of the flight deck effect response.

DETL:
TABLE 1

path(bus ID, source LRU, destination LRU, switches) path(%OIL TEMP, FCC-B, AFC-AU, NONE); path(+28V DC DIM BUS, AIRCRAFT, EIS-P, NONE); signal(source LRU, data ID) signal(CDU-L, MCDU-L-1-354); signal(DAA-L, DAA-L-1-006); signal(FCC-A, FCC-L-1-076); subrule(LRU, rule no., sim. cond. code, failed ID list, condition, response code) subrule(IRU-L, -9999, NWA1/----------/-/--/---/--/--/--/--/-/-, IRU-L-i-1-999-00, c-NONE-X-003, r-IRU-L-999) result(response code, text, data ID list, condition) result(r-ND-L-001, Remove MAP display and display MAP flag, IRU-L-A-3-320-00, c-NONE-X-002) src-sel(LRU, rule no., sim. cond. code, alternate ID list, failed ID list, condition) src-sel(IFMC-L, -S047, NWA1/----------/-/--/---/--/--/--/--/-/-, [IRU-L-A-3-367-00, URU-L-A-3-336-00, IRU-L-A-3-310-00],.quadrature.); src-sel(IFMC-L, -S050, NWA1/----------/-/--/---/--/--/--/--/-/-, [IRU-C-A-3-367-00, IRU-C-A-3-336-00], [IRU-L-A-3-367-00], IRU-L-A-3-366-00, IRU-L-A-3-310-00 [NCD, NO ACTIVITY])

L12: Entry 7 of 26 File: USPT Oct 19, 1999

DOCUMENT-IDENTIFIER: US 5968106 A
TITLE: Aircraft stop-to-position autobrake control system

ABPL:
An aircraft automatic braking system processes the flight crew selected stopping position of the aircraft on the runway via a control display unit (30) and the aircraft's actual position, provided by a global positioning system (34), to generate a stop-to-position deceleration control signal in a provided control logic (36). If the flight crew selects the stop-to-position autobraking mode, the system determines whether or not a stop-to-position autobraking mode meets several predetermined criteria and, if the criteria are met, applies a control signal to the aircraft's braking system (62, 66) such that the aircraft is smoothly braked tending it to stop at the selected runway stopping position. The system eliminates the need for pilot lookup in a manual to determine a desired autobraking setting to choose based on altitude, temperature, approach speed and runway conditions and also operates to reduce pilot workload during limited visibility conditions.

BSPR:
The present invention relates to the aircraft braking art and, in particular, to an aircraft automatic braking system which applies predetermined braking to the aircraft such that the aircraft tends to stop at a selected point on the runway.

BSPR:
Prior to the present invention, aircraft autobrake systems controlled airplane deceleration to one of several aircraft deceleration settings. Thus, if a pilot wished to stop the airplane at a certain point on the runway, for example at a runway exit, it is unlikely that the autobrake system would provide a deceleration setting that matched the stopping distance to the selected runway stop point. The pilot's choice, then, was to select one of the deceleration settings, and, if the airplane was decelerating too quickly, disarm the autobrake system and use pedal braking to avoid stopping short of the desired point. If, however, the airplane was decelerating too slowly, the pilot would again need to revert to pedal braking to increase deceleration to stop the airplane at the selected stopping point. Both of the above conditions result in uneven deceleration that is apparent to the airplane passengers.

BSPR:
It is an object of this invention, therefore, to provide an aircraft stop-to-position autobrake control system.

BSPR:
It is a particular object of this invention to provide an aircraft automatic braking system which controls airplane braking to smoothly decelerate the airplane to a predetermined point on a runway without the requirement for the pilot to look into a flight manual to determine the appropriate autobrake setting to choose based on altitude, temperature, approach speed and runway conditions and, to reduce pilot workload during landings with limited visibility.

BSPR:
Briefly, according to the invention, an aircraft automatic braking system comprises a stop position input for selecting a desired aircraft stopping position on a runway. An aircraft positioning system is provided for determining the aircraft's present position. Control logic compares the aircraft's actual position with the selected stopping position and, in response thereto, predeterminedly decelerates the aircraft such that the aircraft tends to stop at

the selected position.

BSPR:
A method for automatically stopping an aircraft at a selected position on a runway comprises the steps of:

BSPR:
(a) Providing an aircraft brake system which is responsive to input control signals to apply braking to the aircraft;

BSPR:
(b) Determining the aircraft's present position;

BSPR:
(c) Providing a stop position selector for selecting the desired aircraft stopping position on a runway; and

BSPR:
(d) Providing logic control for comparing the aircraft's actual position with the selected stopping position and, responsive thereto, applying a predetermined control signal to the aircraft's brake system such that the aircraft brakes in a manner tending to stop the aircraft at the selected runway position.

DRPR:
FIG. 1A depicts an aircraft on a runway which is positioned a predetermined stopping distance from the desired stopping position;

DEPR:
FIG. 1A illustrates in profile an aircraft 12 which is moving on a runway 14. The aircraft 12 is a predetermined stopping distance from a selected stopping position 16. The selected stopping position 16 may be, for example, a runway exit position from which the pilot should be able to see the desired exit and manually guide (taxi) the airplane off the runway to the airport terminal.

DEPR:
FIG. 1B is a block diagram illustrating the principal components, and their interconnection, of the preferred embodiment of the present stop-to-position automatic braking system. Here, the aircraft's current position is determined by a global positioning system 20. A signal representing aircraft position is routed from the global positioning system 20 to the flight management system 22. The flight management system 22 passes information to and from a flight control databus 24. The flight control databus 24 also connects to an air data inertial reference unit 26 which outputs to the databus information relating to the aircraft's ground speed.

DEPR:
Also connected to the flight control databus 24 is the aircraft information management system 28. The aircraft information management system 28 also connects to the system databus 29, which, in turn, connects to the aircraft brake system control unit 30.

DEPR:
The aircraft positioning system 20 provides a position signal reflecting the position of the aircraft 12 with respect to the desired stopping position 16. The flight management system 22 receives the aircraft's present position and ground speed as input over flight control databus 24 from the air data reference unit 26. The flight management system then generates a stop-to-position (STP) deceleration signal which it outputs to the flight control databus 24. Responsive to the STP deceleration signal, the aircraft information management system 28, assuming the flight crew has selected the stop-to-position deceleration mode, passes the STP deceleration signal over system databus 29 to the brake system control unit 32. In the known manner, the brake system control unit 30 responds to the STP deceleration control signal to automatically apply braking to the aircraft to create the desired aircraft deceleration. In this way, a predetermined braking is applied to the aircraft 12 such that it tends to stop at the selected stopping position 16.

DEPR:
The preferred embodiment of the present invention is the use of a closed-loop

control of target deceleration to control the airplane's deceleration to stop at a precise location on the runway.

DEPR:
The stopping distance is obtained from a global positioning system. The average deceleration is then calculated to stop the airplane within this stopping distance. The formula used to calculate the average deceleration signal, STP.sub.-- DECEL, is derived from the basic equation of motion. It begins with the equation to calculate velocity.

DEPR:
The range for STP.sub.-- DECEL is restricted to positive values above zero to allow the autobrake system to ramp up brake pressure to maintain the airplane at its stopped position. Otherwise, when the present velocity equals the stopping velocity, STP.sub.-- DECEL will equal zero and the autobrake system will not command brake pressure.

DEPR:
The range for the stopping distance, L, is restricted to prevent computational errors when L=0 (the case when the airplane is at its desired position). The minimum value for L, L.sub.min, is based on the resolution of the computed position.

DEPR:
The STP.sub.-- DECEL signal is filtered to eliminate noise from the signal and to limit the rate at which the signal changes. The STP.sub.-- DECEL signal is rate limited to ensure that the bandwidth of the autobrake system is adequate to control the time varying signal. The STP.sub.-- DECEL signal is clamped to prevent excessive deceleration (normal landing autobrake is tested up to A/B MAX) and owing to the fact that the autobrake system can only retard the motion of the airplane (i.e. in the case if STP.sub.-- DECEL is negative the autobrake system can not accelerate the airplane).

DEPR:
Once the TARGET.sub.-- DECEL signal is determined, the autobrake system controls the airplane deceleration as normal. The same control algorithms are used.

DEPR:
FIG. 2 is a more detailed block diagram illustrating the preferred components, and their interconnection, to implement the preferred embodiment of the invention. Interface of the aircraft system to the flight crew is provided through a control display unit (CDU) 31. CDU 31 provides a control pad from which the flight crew enters runway data, such as the selected stopping position on the runway. In addition, the flight crew can enter data related to runway condition, such as wet, dry or frozen or special data related to the runway surface. The runway data from CDU 31 is applied as an input to the control logic 32. Also received as an input to the control logic 32 is the output from the aircraft's global positioning system 34. The global positioning system 34 produces an aircraft position signal representative of the present position of the aircraft on the runway.

DEPR:
Both the runway data from the CDU 31 and the aircraft position data from the global positioning system 34 are routed as inputs to the stop-to-position (STP) deceleration calculation box 36. Also provided as an input to stop-to-position deceleration calculation logic block 36 are signals from an inertial reference system 40 reflecting aircraft deceleration and velocity. In the manner described in detail with respect to the logic flow diagram of FIG. 3, the stop-to-position deceleration calculation logic block 36 produces a calculated STP decel signal which is passed over line 42 to the target deceleration selection logic block 44. Also, logic block 36 produces an engine indication crew alert system (EICAS) signal which is displayed to the flight crew on a provided EICAS display 48. Also coupled to the EICAS display 48 is the output from the target deceleration selection logic block 44. If the stop-to-position autobrake mode has been selected by the flight crew, an appropriate message is displayed on the EICAS display 48.

DEPR:
Also input to the target deceleration selection logic 44 is the output from an

autobrake selector switch 50. The autobrake selector switch 50 is provided on the flight deck and allows the flight crew to select the desired braking mode of the aircraft. As shown, the switch includes the positions "off", meaning the autobrake system is turned off, "DISARM", which is used by the flight crew to temporarily disarm the autobraking system, and then positions "1", "2", "3/STP", "4" and "MAX". The positions "1", "2", "3", "4" and "MAX" all represent predetermined aircraft deceleration settings from a low decel setting of "1" to the highest autobraking decel setting of "MAX". Also, a position "RTO" is provided to apply full brake pressure if the flight crew initiates a refused takeoff.

DEPR:
The target deceleration selection logic 44 processes the stop-to-position deceleration calculation from block 36 and the selected switch deceleration setting from the autobrake selector switch 50 to produce an output target deceleration signal on line 54. This target deceleration signal is compared in summing logic 56 with the inertial reference system (IRS) 40 provided deceleration signal over line 58. The difference between the target deceleration signal on line 54 and the IRS deceleration signal on line 58 represents a deceleration error signal which is output over line 60 to a controller 62. The controller 62 commands the level of brake pressure over line 64 which is applied to the aircraft's dynamics at block 66. Controller 62, line 64 and aircraft dynamics 66 comprise the primary components of the aircraft's braking system, indicated generally at 70. This, in turn, results in an actual deceleration that is measured by the inertial reference system 40. The IRS deceleration signal is transmitted to the autobrake system which then responds to brake the aircraft accordingly.

DEPR:
The actual deceleration signal produced out of the aircraft's dynamics 66 is provided as a feedback signal to the inertial reference system 40.

DEPR:
FIG. 3 is a detailed logic flow diagram illustrating the sequential logical steps performed by the preferred embodiment of the present invention to create the stop-to-position deceleration control signals. Here, pilot input data over a provided control display unit 100 and inertial reference unit data over a provided air data inertial reference unit (ADIRU) 102 are fed to a flight management computer (FMC) 104. Among its other functions, the flight management computer 104 has stored in non-volatile memory applicable runway parameters for all desired airports.

DEPR:
Based on its input data and its stored data, flight management computer 104 outputs the selected aircraft stopping distance X.sub.FINAL over a line 106 and the desired aircraft velocity V.sub.FINAL.sup.2 over line 108.

DEPR:
A global positioning system 110, in the known manner, provides an output present aircraft position signal, X, over line 112 to a logic block 114. Logic block 114, in the manner shown, calculates the aircraft's stopping distance L and determines whether the stopping distance L is greater than a predetermined minimum value L.sub.MIN. The output from logic block 114 is provided to logic block 116 which then calculates the deceleration value as shown.

DEPR:
The output from logic block 116 is passed to logic block 118 which calculates the aircraft's stop-to-position decel signal as equaling the deceleration value from block 116 plus a deceleration offset value. In addition, logic block 118 determines if the stop-to-position deceleration signal is greater than or equal to a required minimum stop-to-position deceleration value.

DEPR:
Returning to decision point 220, if the stop-to-position deceleration data is valid, decision point 224 is entered, and the system determines whether or not the autobrake "3/STP" position is selected. If the "3/STP" autobrake position has not been selected, the system again increments to block 222 to set the stop-to-position autobrake advisory message active. However, if, at decision point 224 the autobrake "3/STP" position is selected, the system enters block

230. At block 230, the system sets the target deceleration value equal to the stop-to-position deceleration value. Then, out of block 230, the target deceleration signal is low pass filtered at block 232 to limit the rate at which the deceleration control signal can change to ensure that the bandwidth of the aircraft brake system is adequate to process the filtered command and control signal. The filtered signal is then passed from block 232 to block 234 wherein the stop-to-position autobrake memo message is set to its active mode. Out of block 234, the output target deceleration value is provided via block 206.

DEPR:
The pilot is alerted that STP autobrake is inoperative when the STP AUTOBRAKE ADVISORY message appears on the EICAS display. The STP AUTOBRAKE ADVISORY message shall be transmitted when all of the following conditions are met.

DEPR:
A DECEL.sub.-- OFFSET is added to the calculated DECEL level to ensure the airplane can be stopped before the exit position.

DEPR:
In summary, a stop-to-position aircraft automatic braking system has been described in detail. Whereas a preferred embodiment of the invention has been described, it should be apparent that many modifications and variations thereto are possible, all of which fall within the true spirit and scope of the invention.

DEPL:
Position is determined by integrating equation (1). ##EQU1## where, x.sub.final =final airplane position

DEPL:
The pilot is alerted that STP autobrake is selected when the STP AUTOBRAKE memo message appears on the Engine Indication and Crew Alert System (EICAS) display. The STP autobrake system also provides a signal to the FMC indicating that STP AUTOBRAKE is selected. The STP AUTOBRAKE MEMO message shall be transmitted when all of the following conditions are met.

DEPU:
DECEL.sub.-- MARGIN: An extra increment of deceleration which is added to the STP.sub.-- DECEL level that ensures the airplane stops short of the desired exit despite some inaccuracy in the STP.sub.-- DECEL level.

DEPU:
DECISION.sub.-- DISTANCE: The distance from the desired exit at which the decision must be made as to whether the maximum STP.sub.-- DECEL level is capable of stopping the airplane within the remaining distance from the exit.

DEPU:
TD.sub.-- MARGIN: The margin allowed for an airplane to land within the initial estimated touchdown point on the runway.

DEPV:
v.sub.final =final airplane velocity

DEPV:
v=the current airplane velocity

DEPV:
a=average airplane acceleration

DEPV:
x=the current airplane position

DEPW:
C. TD.sub.-- POSITION is >TD.sub.-- MARGIN. (This provision prevents use of bad data in the event the airplane lands or touchdown on a different runway without re-selection of STP autobrake, for example in the case of an aborted landing).

CLPR:
1. An aircraft automatic braking system comprising:

CLPR:
2. An aircraft automatic braking system for automatically stopping the aircraft at a selected position on the runway, the system comprising:

CLPR:
3. The system of claim 2 wherein said logic control means further includes filtering means for limiting the rate at which said control signal changes to ensure that the bandwidth of said aircraft brake system is adequate to process the filtered control signal.

CLPR:
4. The system of claim 2 wherein said logic control means further includes control signal clamping means to prevent excessive aircraft braking.

CLPR:
5. The system of claim 3 wherein said logic control means further includes control signal clamping means to prevent excessive aircraft braking.

CLPR:
6. A method for aircraft automatic braking comprising the steps of:

CLPR:
7. A method for automatically stopping an aircraft at a selected position on a runway, the method comprising the steps of:

CLPR:
8. The method of claim 7 wherein the logic control means further performs the step of filtering the control signal to limit the rate at which the control signal changes to ensure that the bandwidth of the aircraft brake system is adequate to process the filtered control signal.

CLPR:
9. The method of claim 7 wherein the logic control means performs the further step of clamping the control signal to thereby prevent excessive aircraft braking.

CLPR:
10. The method of claim 8 wherein the logic control means performs the further step of clamping the control signal to thereby prevent excessive aircraft braking.

CLPV:
(a) stop position input means for selecting a desired aircraft stopping position on a runway;

CLPV:
(b) an aircraft positioning system for determining the aircraft's present position; and

CLPV:
(c) control means for continuously comparing the aircraft's actual position with said selected stopping position and, in response thereto, predeterminedly decelerating said aircraft such that the aircraft tends to stop at said selected position.

CLPV:
(a) an aircraft brake system which is responsive to input control signals to apply braking to the aircraft;

CLPV:
(b) an aircraft positioning system for determining the aircraft's present position;

CLPV:
(c) a stop position selection means for selecting the desired aircraft stopping position on a runway; and

CLPV:

(d) logic control means for continuously comparing the aircraft's actual position with the selected stopping position and, in response thereto, applying a predetermined control signal to said aircraft's brake system such that the aircraft brakes in a manner tending to stop the aircraft at said selected runway position.

CLPV:
(a) providing for the input of a selected aircraft stopping position on a runway;

CLPV:
(b) determining the aircraft's present position; and

CLPV:
(c) continuously comparing the aircraft's present position with the selected stopping position and, responsive thereto, predeterminedly decelerating said aircraft such that the aircraft tends to stop at said selected position.

CLPV:
(a) providing an aircraft brake system which is responsive to input control signals to apply braking to the aircraft;

CLPV:
(b) determining the aircraft's present position;

CLPV:
(c) providing a stop position selector for selecting the desired aircraft stopping position on a runway; and

CLPV:
(d) providing logic control means for continuously comparing the aircraft's actual position with the selected stopping position and, responsive thereto, applying a predetermined control signal to the aircraft's brake system such that the aircraft brakes in a manner tending to stop the aircraft at the selected runway position.

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L12: Entry 11 of 26 File: USPT Dec 17, 1996

DOCUMENT-IDENTIFIER: US 5586065 A
TITLE: Method and apparatus for minimizing aircraft cabin noise

ABPL:
Aircraft cabin noise and engine vibration are monitored at selected cabin and engine locations (51a/51b), respectively. An optimizing equation uses aircraft cabin noise information to separately determine for each engine a balance solution (60) that minimizes aircraft cabin noise at the selected cabin locations over the engine RPM range of interest. Next, the balance solutions are used to predict the engine vibration levels (63) that will be produced if the balanced solution is implemented. Then a test (65) is made to determine if the predicted engine vibration levels are acceptable, i.e., below a predetermined level. If acceptable, the balance solutions are used to select balance weights suitable for the engines being balanced (66) and the result displayed (67) for implementation by engine maintenance personnel. If the predicted vibration level is unacceptable, a new balance solution is determined for each engine (68) using the optimizing equation constrained by the allowable vibration level.

BSPR:
The present invention relates to vehicle cabin noise and, more particularly, to a method and apparatus for minimizing vehicle (e.g., aircraft) cabin noise caused by the imbalance of the engines of the vehicle.

BSPR:
As will be readily understood from the following description, while the present invention was developed for use in minimizing aircraft cabin noise potentially, the invention can be used in any type of vehicle to minimize any objectionable environmental parameters, including noise, in the cabin of the vehicle created by the imbalance of the engine(s) powering the vehicle.

BSPR:
One of the annoyances of modern air travel is the level of noise in an aircraft cabin during flight. Annoying aircraft cabin noise comes in two forms--audible form and tactile form. The audible form of noise is the sound pressure level heard by the passenger and crew of the aircraft. The tactile form of noise is the vibration felt by passengers and crew. As used in this application the word noise is intended to cover audible noise, or tactile noise, or both.

BSPR:
Excessive noise levels can cause aircraft passenger and crew discomfort. One source of aircraft cabin noise is engine vibration. Engine vibration is transferred through aircraft structure into the cabin of the aircraft and manifests itself as cabin noise. In addition to causing passenger and crew discomfort, engine vibration can decrease the efficiency of an engine, significantly reduce engine life, and increase engine maintenance costs.

BSPR:
To fully understand engine vibration, it is necessary to understand the operation of the jet engines that power modem aircraft. Most modem commercial aircraft are powered by high-bypass jet engines. High-bypass jet engines have a large number of rotating elements. The rotating elements can be grouped accordingly to the relative speed of rotation. Some of the rotating elements form a low-speed rotating system and some of the rotating elements form a high-speed rotating system. While, during in-flight operation, both the low-speed rotating system and the high-speed rotating system can be a source of unwanted engine vibration, the primary source of passenger and crew discomfort is the low-speed rotating system.

BSPR:
Engine vibration is caused by an imbalance in the rotating system producing the vibration. In order to reduce structurally transmitted vibration, engine manufacturers have modified the locations where engine vibration is transferred from the rotating system causing the vibration to the air frame of the aircraft. These solutions to the engine vibration problem include the use of damped bearings and vibration isolators.

BSPR:
Another way of reducing structurally transmitted vibration that has been implemented by aircraft operators in the past is to balance the rotating systems of aircraft engines on a regular basis. Engine balancing is well known in the aircraft art. It involves the attachment of weights at specific locations on the rotating system to be balanced. In many respects, the balancing of a high-bypass jet engine is analogous to the balancing on an automobile tire prior to mounting the tire on an automobile. Placing weights of specific mass at specific radial locations along the axis of a rotating system considerably reduces the vibration of the rotating system and, thus, the noise created by the vibration. The specification of the location and amount of weight to be applied to the rotating system in order to balance the rotating system is referred to as the balance solution for the rotating system.

BSPR:
In order to determine balance solutions for the rotating systems of aircraft engines, it is necessary to obtain vibration data. Vibration data is a measure of the amount of vibration that an engine is producing at various locations as the engine is operated at various speeds. Until recently, vibration data was gathered at an engine balancing facility located on the ground. More recently, engine vibration data has been gathered during flight. Regardless of how gathered, after vibration data is obtained, the vibration data is used to obtain a balance solution that attempts to minimize the vibration of the engine producing the data.

BSPR:
Unfortunately, all of the prior art methods used to obtain balance solutions operate under the assumption that minimizing engine vibration will also minimize cabin noise. This assumption is flawed for two reasons. First, only two locations are monitored on current engine designs. Many more than two locations would be required to cover all of the load paths an engine can use to transmit energy into the cabin. Minimization of vibration levels at only two locations does not necessarily mean that an engine is considered well balanced. Second, unbalances can lie along the interior length of the low rotor at planes that are not coincident with the fan and the last stage of the turbine. These unbalances can be due to interior blade unbalances in the engine stack up and also to rotor shaft coupling and bearing misalignments. It is not possible to completely balance an engine with access to only the exterior of the engine (i.e., the fan and last stage of the turbine). Engine balancing, therefore, is always a compromise because different balance solutions have different effects on vibration at different engine speeds, and at different locations. The criteria for success in balancing depends on how much of the dynamic picture of an engine one chooses to view. Because of the foregoing and other dynamic factors, minimizing engine vibration does not always directly correlate with minimizing aircraft cabin noise.

BSPR:
In accordance with the present invention, an improved method and apparatus for reducing passenger discomfort by taking into account actual aircraft cabin noise as well as engine vibration is provided. More specifically, in accordance with this invention, aircraft cabin noise and engine vibration are both monitored at selected cabin and engine locations, respectively. An optimizing equation uses the monitored aircraft cabin noise data to separately determine for each engine a balance solution that will minimize aircraft cabin noise at the selected cabin locations. Next, the balance solutions are used to predict the engine vibration that will be produced if the balance solutions are implemented. Then a test is made to determine if the predicted engine vibration levels are acceptable, i.e., below a predetermined level. This acceptable level may be based on allowable EBU (engine build-up units) vibration to insure component life, and overall engine

health considerations. If acceptable, the balance solutions are used to select balance weights suitable for the engines being balanced and the result displayed for implementation by engine maintenance personnel. If the predicted engine vibration levels are unacceptable, a new balance solution is determined for each engine using the optimizing equation constrained by the allowable vibration level. The monitored cabin noise can be limited to audible noise or tactile noise, or can include both types of noise.

BSPR:
In accordance with yet other aspects of this invention, audible aircraft cabin noise is monitored by microphones, which detect sound pressure. Cabin tactile vibration, where applicable, is monitored by cabin accelerometers located in the vicinity of the undesirable vibration (often at wing center section seats over the wing spar).

BSPR:
where C.sub.i is the predicted noise at location i in the cabin of the aircraft; C*.sub.i is the measured noise level at location i; N.sub.f.sup.i is the noise influence coefficient at location i due to a unit FAN imbalance; and N.sub.i.sup.l is the noise influence coefficient at location i due to a unit LPT imbalance. FAN and LPT in the equation are fan and low-pressure turbine (LPT) balance weights each at their own independent angular position. That is, FAN is the pan of the balance solution relating to the fan of the region, and LPT is the pan of the balance solution relating to the low-pressure turbine, sometimes called the low-speed rotor, of the engine. The noise influence coefficients are defined as a change in the response of the parameter divided by a change in engine unbalance. If the parameter is audible aircraft noise, the noise influence coefficient is defined as a change in sound pressure response (in actual magnitude, not in decibels) divided by a change in engine unbalance. If the parameter is cabin tactile vibration, the noise influence coefficient is defined as a change in cabin vibration response divided by a change in engine unbalance.

BSPR:
As will be readily appreciated from the foregoing description, rather than balancing engines in a manner designed to minimize vibration as measured at the AVMs, the present invention balances engines in a manner designed to minimize aircraft cabin noise. In some instances, the implementation of the present invention could result in an increase in engine vibration over some rpm ranges. A constraint is placed on engine imbalance in order to prevent such imbalance from exceeding a predetermined level, even though this could result in a further decrease in cabin noise.

DRPR:
FIG. 1 is a side cut-away pictorial diagram of a typical high-bypass jet engine of the type used to power commercial aircraft;

DEPR:
Prior to describing the presently preferred embodiment of the invention, a brief description of a high-bypass jet engine of the type commonly used to power modern commercial aircraft is described followed by a brief description of electronic circuitry suitable for converting the signals produced by accelerometers mounted on an aircraft engine to detect engine vibration into displacement signals.

DEPR:
High-bypass jet engines of the type pictorially illustrated in FIGS. 1 and 2 and described above are well known in the aircraft art. Most modern high-bypass jet engines include all of the components illustrated in FIGS. 1 and 2 and described above, including the rotor speed sensor 27, the rear accelerometer 29, and the forward accelerometer 31. For example, the model GE90 engine manufactured by General Electric, the model PW4084 engine manufactured by Pratt & Whitney, and the model Trent 800 engine manufactured by Rolls Royce all include a rotor speed sensor, a rear accelerometer, and a-front accelerometer. Originally, the accelerometers included in aircraft engines were primarily used to provide signals to warning devices. In recent years, the signals produced by engine accelerometers have been provided to the Engine Indicator and Crew Alerting System (EICAS) of commercial jet aircraft. The EICAS alerts the crew of an engine malfunction if excessive vibration is detected. More recently, the accelerometer signals provided to the EICAS have also been utilized to provide information for use in engine balancing systems. More specifically, the accelerometer signals and

electronic conditioning circuitry have been used to create airborne vibration monitors (AVMs). AVMs produce signals that, when suitably analyzed, provide data regarding the angular position and amount of weight to be applied to the jet engines of an aircraft to balance the rotating systems of the engine. The angular position and amount of weight required to balance the rotating systems of an aircraft engine is commonly called the balance solution.

DEPR:
The purpose of the balance solution is to reduce cabin noise as well as increase the efficiency of the engine, increase engine life, and decrease engine maintenance cost. Unfortunately, the balance solution determined by prior art systems does not always reduce aircraft noise to a minimum because factors other than engine balance are involved. As will be understood from the following description of the preferred embodiment of the invention illustrated in FIG. 4, the present invention is directed to minimizing aircraft cabin noise by taking into consideration the actual cabin noise of an aircraft produced by engine vibration.

DEPR:
Noise signals produced by a plurality of. microphones 51a, or accelerometers 51b, or both are both positioned in the cabin of an aircraft 53, and vibration displacement signals produced by the AVMs are converted from analog form to digital form. See block 55. The analog-to-digital conversion includes one or more steps to insure that the digital representation of the low rotor tone signal is periodic in the record length or ensemble. The engine speed sensor signal provides the information required for these steps to occur. The engine speed sensor signal also provides a means for generating a once per revolution TTL (transistor transitor logic) pulse that is used as a phase reference, indicating when the sampling is to begin. Thereafter, an order tracked fast-Fourier transformation (FFT) is performed on the digital signals resulting from the analog-to-digital (A/D) conversion. These steps are well known in the art of data acquisition as order tracking. Currently, the best order tracking method to be used in the practice of this invention is described in a paper by R. Potter and M. Gribler, Computed Order Tracking Obsoletes Older Methods, SAE Paper 891131, Noise and Vibration Conference, Traverse City, Mich., May 16-18, 1989.

DEPR:
Order tracking eliminates noise contained in the A/D converted signals that is non-synchronous to the rotational speed of the low-speed shaft 13 and obtains a measurement of the tone of the low-speed shaft with minimized discrete Fourier transform leakage. The tone is tracked over the RPM range of the engine over which noise is to be minimized. This could be the cruise RPM range, the hold RPM range, the take-off RPM range, the landing RPM range, or all of the RPM ranges over which the aircraft operates. The hereinafter-described influence coefficients have to be determined for a sufficient number of discrete points in the range of interest to make an actual embodiment of the invention viable.

DEPR:
Next, a test is made to determine if the balance weights on any of the aircraft engines have been changed. See block 57. In this regard, when the balance weights on the balance ring or rear blades of the low-pressure turbine of any of the aircraft engines is changed, the change is recorded in a memory (not shown) associated with a hereinafter-described maintenance access terminal (MAT) located on-board the aircraft. The block 57 test checks this memory to determine if any balance weight change has occurred since the last time the test was performed.

DEPR:
The influence coefficients are defined as the change in the related cabin response parameter (sound pressure or vibration) divided by the related change in engine balance. The responses, influence coefficients, and balances are all complex numbers. If a change in the balance of an engine has been made (and the data for at least one baseline engine run has been stored) at block 58, new influence coefficients corresponding to the change in balance are calculated. In this manner, the influence coefficients are continuously updated or refined each time a system formed in accordance with this invention is activated. Ideally, influence coefficients will not vary over time, or from aircraft to aircraft. In such instances, the influence coefficients can be loaded when an engine is installed and the update calculation sequence eliminated.

DEPR:
If the engine balance weights have not changed, or after the updated influence coefficients have been computed and stored, the Fourier transformed signals derived from the noise signals produced by the microphones 51a or accelerometers 51b are used by an optimizing equation to separately determine for each engine a balance solution (e.g., fan and low-pressure turbine corrective weights and angular positions) that will minimize aircraft cabin noise at the locations of the microphones 51a, or accelerometers 51b, or both. The preferred form of the optimizing equation is:

DEPR:
If the predicted new engine vibration levels at the AVM locations are not below acceptable vibration levels, the optimizing Equation (1) is solved again with the constraint that the allowable AVM levels (D.sub.j) lie below D.sub.a, where D.sub.a is the allowable AVM vibration level. See block 68. Thereafter, the balance solution, i.e., the FAN and LPT corrective weight and angular position values derived from resolving the optimizing equation with this constraint are used to select balance weights for the type of engine on the aircraft 51 and the result displayed on the maintenance access terminal (MAT) display 69.

DEPR:
As will be readily appreciated from the foregoing description, the invention provides a method and apparatus that minimizes aircraft cabin noise produced by engine vibration. Rather than balancing engines to minimize engine vibration, the invention balances engines to minimize cabin noise. If necessary, limits are placed on the balancing solution that prevents the balancing solution from producing an output that could detrimentally unbalance the engines.

DEPR:
The invention incorporates an optimizing equation that is solved to determine the fan and low-pressure turbine corrective weights that minimize low rotor synchronous noise. The tone transmitted to the cabin that creates the noise is produced by the low-speed rotating systems of the aircraft engines. Order tracking is used to eliminate all noise that is non-synchronous with the tone produced by the low-speed rotating system and to get a measurement of the tone with minimized discrete Fourier transform leakage. The tone must be tracked over an RPM range of the engines that defines the control range over which noise is to be minimized. The engine RPM range may be the take-off range, the climb range, the cruise range, the descent range, the hold range or all RPM ranges over which the engines operate, or the RPM range over which the aircraft has a noise transmission/amplification problem. Obviously, a sufficient number of influence coefficients at discrete points in the control range must be gathered.

DEPR:
Each engine must be optimized separately. For a given engine, the necessary data is gathered when the other engine(s) is slightly retarded or advanced so that the engine tones do not overlap. While the easiest way to achieve this result is for the other engines to be operated out of the octave band of the engine providing the data, with order tracking this is not necessary. The RPM of the engines can remain much closer together. Order tracking with a sufficient number of averages eliminates the non-coherent contributions from other engines, provided the RPM of the other engines is not exactly the same as the RPM of the engine providing the data. The greater the RPM differential, the fewer averages required. Since the data collection period is rather brief, the RPM mismatch period is relatively brief. Thus, the data collection period has very little, if any, impact on normal aircraft operation.

CLPR:
11. A method of determining the corrective weight to be added to the low-speed rotating systems of the jet engines powering an aircraft in order to minimize the noise in the cabin of the aircraft created by an imbalance of the low-speed rotating systems of the jet engines, said method comprising the steps of:

CLPR:
18. An apparatus for determining the corrective weight to be added to the low-speed rotating systems of the jet engines powering an aircraft to minimize the noise in the cabin of the aircraft created by an imbalance of the low-speed rotating systems of the jet engines, said apparatus comprising:

CLPV:
monitoring the noise in the cabin of the aircraft to produce monitored cabin noise data that describes the noise in the cabin of the aircraft created by the vibration of the jet engines powering the aircraft produced by the imbalance of the low-speed rotating systems of the jet engines; and

CLPV:
based on said monitored cabin noise data, determining a balance solution for each jet engine, that defines the angular position and corrective balance weights to be added to the jet engine to minimize the noise in the cabin of the aircraft created by the vibration of the jet engine produced by the imbalance of the low-speed rotating systems of the jet engine.

CLPV:
C.sub.i is the predicted noise level at location i in the cabin of the aircraft;

CLPV:
C*.sub.i is the measured noise level at location i in the cabin of the aircraft;

CLPV:
a monitoring system including noise sensors for monitoring the noise in the cabin of the aircraft to produce monitored cabin noise data that describes the noise in the cabin of the aircraft created by the vibration of the jet engines powering the aircraft produced by the imbalance of the low-speed rotating systems of the jet engines; and

CLPV:
a calculating system coupled to said monitoring system for receiving the monitored cabin noise data and using the monitored cabin noise data to determine a balance solution for each jet engine that defines the angular position and corrective balance weights to be added to the low-speed rotating system of the jet engine to minimize the noise in the cabin of the aircraft created by the vibration of the jet engine produced by the imbalance of the low-speed rotating systems of the jet engine.

CLPV:
C.sub.i is the predicted noise level at location i in the cabin of the aircraft;

CLPV:
C*.sub.i is the measured noise level at location i in the cabin of the aircraft;

L12: Entry 21 of 26 File: USPT Sep 17, 1991

DOCUMENT-IDENTIFIER: US 5050081 A
TITLE: Method and system for monitoring and displaying engine performance parameters

ABPL:
The invention is a method and system for monitoring and directly displaying the actual thrust produced by a jet aircraft engine under determined operating conditions and the available thrust and predicted (commanded) thrust of a functional model of an ideal engine under the same determined operating conditions. A first set of actual value output signals representative of a plurality of actual performance parameters of the engine under the determined operating conditions is generated and compared with a second set of predicted value output signals representative of the predicted value of corresponding performance parameters of a functional model of the engine under the determined operating conditions to produce a third set of difference value output signals within a range of normal, caution, or warning limit values. A thrust indicator displays when any one of the actual value output signals is in the warning range while shaping function means shape each of the respective difference output signals as each approaches the limit of the respective normal, caution, and warning range limits.

BSPR:
The invention is a method and system for monitoring and displaying engine performance parameters and more particularly to a method and system for simultaneously monitoring and visually displaying, a plurality of the performance parameters of an aircraft engine during operation, including the predicted value of maximum available thrust or power, the predicated amount of thrust commanded, and the thrust then actually being produced within the critical limits of the predicted nominal and actual values of the plurality of monitored engine performance parameters.

BSPR:
In general conventional single and multiple engine aircraft control systems include individual instruments that provide operational data (engine performance parameter measurements) to the pilot based on the outputs of a plurality of individual sensors.

BSPR:
Some electronically generated, microprocessor driven displays in multiple engine jet aircraft, such as the Boeing 757/767 manufactured by Boeing Commercial Airplane Company, P.O. Box 3707, Seattle, Wash. 98124, use a similar approach, except the outputs from two or more sensors may be presented on a single electronic display.

BSPR:
For instance, currently, before making a thrust or power adjustment during take off, pilots of multiple engine jet aircraft use charts to calculate the amount of thrust available from each engine and then using this reading to set either the engine pressure ratio (EPR) or low pressure compression rotational speed for each engine. In addition, the pilot must also cross-check the several engine performance parameters for each engine such as exhaust gas temperature (EGT), fuel flow (FF), oil pressure, temperature, and quantity to assure all are within the operational limits of each engine as provided by the manufacturer or based on the pilots experience and judgement before changing the thrust of the engines. This is an indirect, time consuming thrust control process.

BSPR:
An object of the invention is to provide a method and system for monitoring and displaying aircraft engine performance parameters permitting a pilot to make direct operational changes in thrust or power based solely on engine performance parameter that are simultaneously monitored and displayed.

BSPR:
A further object of the invention is to provide a method and system for monitoring and displaying aircraft engine performance parameters such as available thrust, the predicted amount of thrust commanded, and the actual amount of thrust being produced within the critical limits of predicted normal and actual engine performance parameters.

BSPR:
A further object of the invention is to provide a method and system for directly displaying the difference between predicted and actual performance parameters of a jet aircraft engine that are within determined limits, of a range of values.

BSPR:
Another object of the invention is to provide a method and system for simultaneously displaying the differences between the predicted and actual values of a plurality of engine performance parameters for one or more jet aircraft engines in a single display, the actual values being displayed in a first format and the difference values being displayed in a second format indicative of determined limits of said difference values.

BSPR:
Still another object of the invention is to provide a monitoring and display system and method in which difference signals are shaped as their values approach the limit of one or more ranges of limit values.

DRPR:
FIG. 1 schematically illustrates a preferred embodiment of a monitoring and display system in accordance with the invention:

DRPR:
FIG. 2 illustrates the thrust indicator display and monitoring indicator display as shown in FIG. 1 in greater detail; and

DRPR:
FIG. 3 is a diagram illustrating the manner in which noise or jitter is reduced in the monitoring indicator display by using a shaping function.

DEPR:
Referring to the drawings, FIG. 1 illustrates a preferred embodiment of the invention for use in single or multiple engine jet aircraft as generally comprising an engine monitoring system section 10 interconnected between an aircraft system section 11 and a display section 12.

DEPR:
Aircraft system section 11 includes a commercially available air data computer 13, such as a model number A.320 ADIRS air data computer manufactured by Honeywell responsive to conventional jet aircraft sensors S mounted and arranged to provide digital output signals 14, 16, and 17, representative respectively of the operating conditions of external air temperature, air pressure, and the mach or airspeed of the aircraft as a percentage of the speed of sound at ground level.

DEPR:
Aircraft system section 11 also provides parallel digital output signals 18 and 19 representative of the aircrafts throttle position as controlled by a pilot, the output signal 18 being directly connected to control for example a respective jet engine 20 such as a model JT8D-7 jet engine manufactured by Pratt and Whitney, (address). Conventional aircraft system sensors S' responsive to the operation of the jet engine 20 provide a first group of digital output signals representative of the position of bleed valve 21 and the engine gas pressure ratio 22, and a first set of digital output signals representative of N.sub.1 (low pressure compressor rotational speed) 23, N.sub.2 (high pressure compressor rotational speed) 24, exhaust gas temperature 25, fuel flow 26, oil pressure 27,

oil temperature 28, and oil quantity 29.

DEPR:
For example an engine indication and crew alerting system (EICAS) manufactured by the Collins Air Transport Division, Rockwell International Corporation, Cedar Rapids, Iowa 52498 may be programmed to provide the engine model subsection 31, which includes subsections 42 and 43 for calculating the ideal thrust limits and actual thrust respectively, and subsection 41 and 44 for normalizing the predicted and actual thrust respectively. Output signals 45, 46, and 50 from subsection 42 and output signal 47 from subsection 44 along with output signal 59 from subsection 41 are connected to a thrust indicator 48 in display section 12.

DEPR:
The first and third sets of output signals 23-29 and 82-88 are connected to a monitoring indicator 91 in the display section 12. Monitoring indicator 91 generates an output signal 92 connected to thrust indicator 48 when any one of the monitored performance parameters of engine 20 exceeds a determined or off-limit values which condition is also displayed by thrust indicator 48.

DEPR:
Rejecting unnecessary terms, this regression serves to reduce the complexity of the final functional model. For instance, when this analysis is applied to a model JT8D-7 jet engine made by Pratt and Whitney Aircraft Group, 400 Main Street, Commercial Products Division, East Hartford, Conn. 06108, the functional model for the ideal engine performance parameter is of the following form:

DEPR:
Shaping Function subsection 81 receives as input the output signals 72-78 from the Worst Case Selector Function 71. Referring to FIGS. 2 and 3, to obtain proper deviation bar sizes on the monitoring display 91, the Shaping Function subsection 81 uses the following values:

DEPR:
Continuing the description of display section 12, FIG. 2 illustrates both the thrust indicator 48 and monitoring indicator 91 in greater detail. The thrust indicator 48 provides aircraft control information directly to the pilot based upon the actual and ideal functional model performance parameters of two engines 20 designated as left (L) and (R) right respectively. The pilot may use this control information directly in making power adjustments without any additional "look-up" of engine performance data.

DEPR:
The monitoring indicator 91 simultaneously provides comparison information relative to determined limits of the actual and "ideal" engine performance parameters in both digital and graphic form. In addition the monitoring indicator 91 may provide an output signal 92 that preempts the thrust indicator 48 display when anyone of the monitored engine performance parameters exceeds a determined value as previously described as an added safety feature.

DEPR:
A colored (yellow) thrust reference pointer 101 provided for each scale 93 and 94 that displays a reference value selected by the pilot for each engine 20L and 20R. This selected value, in percent of maximum available thrust, is presented in digital form (98% for example) at reference point 101 for a determined time interval (5 seconds for instance) following a change in the selected reference value.

DEPR:
The thrust indicator 48 also includes a colored (white) vertical thrust predictor bar 102 which overlays a current or actual thrust bar 103, both of which are positioned between and parallel to the respective scales 93 and 94. The thrust predictor bar 102 is responsive to and displays the calculated and pilot commanded thrust of the "ideal" functional model independent of the actual engines 20L and 20R but based on their then current operating conditions as determined by digital output signals 14, 16, 17, 18, and 21. The predicted commanded thrust is presented both as the colored (white) bar 102 and as a predictor pointer 104 that also includes a digital readout in the percent of maximum available thrust represented by the predicted thrust.

DEPR:
Each pair of actual thrust bars 103 is responsible to and displays the value of the actual thrust represented by a digital output signal 47 for the respective engine 20L or 20R with which associated. The actual thrust indicator bars 103 are multi-colored, reflecting their respective operating values by color-green when outside both the caution range 97 and warning range 96, of scales 93 and 94, yellow in the caution range 97 of the scales 93 and 94, and red in the warning range 96 of the scales 93 and 94. Under normal steady-state operating conditions the position, of the predictor bars 102 and actual thrust bars 103 relative to the respective scales 93 and 94 should be generally in agreement.

DEPR:
Referring to FIGS. 2 and 3, monitoring indicator 91 includes a plurality of side-by-side pairs of vertical bar deviation indicators 111-117 for the performance parameters N.sub.1, EGT, N.sub.2, fuel flow (FF), oil pressure, oil temperature, and oil quantity respectively for the engines 20L and 20R. Each bar indicator 111-117 displays the difference between the actual and estimated value of each performance parameter for each engine 20L and 20R as represented by the output signals 82-88 respectively from the shaping function subsection 81 as previously described. To reduce visual noise or jitter on the display 91 caused by the deviation bars 111-117 growing slightly around the O valve, a shaping function as shown in FIG. 3 is applied to the input deviation to the display. The shaping function diminishes this jitter around the O point, in the center of the caution range CR, and at the limit of the warning range WR. The shaping function also serves to increase the movement of the bars 111-117 around the transition areas between the normal and caution ranges NR and CR and between the caution and warning ranges CR and WR. This shaping function is expressed as follows: ##EQU7## The actual value of each performance parameter of each engine 20L and 20R is digitally displayed above each bar deviation indicator 111-117.

DEPR:
When the deviation of any one of the performance parameters of either engine 20L or 20R reaches the red warning range WR, this condition will be indicated by both a red deviation bar 111-117 and a corresponding red digital readout. A digital warning signal 92 input to the thrust indicator 48 actuates the coloring of bar 103 to red warning for the associated engine 20L or 20R preempting all other engine parameter indicators in the display 12.

DEPR:
To produce the actual display elements, as shown in FIG. 2 and which are generated by section 12, assume that the display is a conventional cathode ray tube having a face size that is 1000 units across and 575 units high and with the coordinate origin (x=0, y=0) in the lower left corner of the display face.

DEPR:
The invention thus continuously and simultaneously displays to a pilot the maximum amount of thrust or power an engine or engines can produce under the current operating conditions, the amount of thrust commanded; and the actual thrust the engine or engines are producing. Additionally, all normal engine thrust limiting parameters (N.sub.1, EGT, and N.sub.2) are continuously and simultaneously used to compute the thrust range markings displayed on thrust indicator 48, eliminating the need for cross-checking other engine settings when setting engine thrust or power.

DEPR:
The display of the predicted thrust of an "ideal" engine under the current operating conditions is independent of and permits a direct comparison check between the performance of the operating engine 20 or engines 20L and 20R and the "ideal" or functional model. Thus, the invention determines what the thrust performance parameters of an "ideal" functional model engine should be and compares them simultaneously and continuously against the corresponding actual engine thrust performance parameters.

DEPR:
Presenting this information in the form of the column-deviation bars 111-117 permits holistic viewing as the time required to acquire the displayed engine performance parameters is constant relative to the number of displayed engine performance parameters. That is, it requires no more time to process and visually display one set of engine performance parameters than two in accordance with the

invention. Thus, the method and systems in accordance with the invention becomes more effective as either the number of engines or engine performance parameters for each engine increases.

CLPR:
1. A method of monitoring and displaying the actual, predicted, and available thrust of an aircraft engine under determined operating conditions comprising the steps of:

CLPR:
7. A method of monitoring and displaying one or more selected performance parameters of an aircraft engine comprising the steps of:

CLPR:
15. In a system for monitoring and displaying one or more actual performance parameters of a jet aircraft engine under determined operating conditions the improvement comprising:

CLPR:
22. The invention as defined in claim 4 wherein said first group of output signals includes an EPR output signal representative of the engine pressure ratio of said jet engine under said determined operating conditions and said second means includes means responsive to said determined operating conditions and said EPR output signal for calculating the actual thrust of said aircraft engine and generating an output signal representative thereof;

CLPR:
23. The invention as defined in claim 22 wherein said computer means includes means responsive to said determined aircraft operating conditions for calculating and generating output signals representative of the values oF the predicted and available thrusts of said functional model of said aircraft when operated under said determined operating conditions: and

CLPR:
24. The invention as defined in claim 23 wherein said respective display means include a common display panel and said values of said actual, predicted, and available thrusts are simultaneously displayed.

CLPR:
26. A system for monitoring and displaying the actual, predicted and available thrust of a jet aircraft engine under determined operating conditions comprising

CLPV:
calculating the actual thrust of said aircraft engine under said determined operating conditions and generating an output signal representative thereof:

CLPV:
calculating the predicted thrust of a functional model of said aircraft engine under said determined operating conditions and generating an output signal representative thereof:

CLPV:
calculating the available thrust of said functional model of said aircraft engine under said determined operating conditions: and

CLPV:
generating a first set of digital output signals representative of one or more performance parameters of said aircraft engine under said determined operating conditions;

CLPV:
calculating the value of one or more performance parameters of said functional model of said aircraft under said determined operating conditions and corresponding to the performance parameters of said aircraft engine;

CLPV:
sensing the value of said one or more selected performance parameters of said aircraft engine under determined operating conditions:

CLPV:
predicting the value of corresponding performance parameters of an "ideal" functional model of each of said one or more performance parameters of said aircraft engine under said determined operating conditions:

CLPV:
computer means for predicting the value of one or more performance parameters of an "ideal" functional model of said jet aircraft engine using said determined operating conditions, said predicted performance parameters corresponding to said one or more actual performance parameters of said aircraft engine:

CLPV:
a display panel, including a monitoring indicator display means for simultaneously displaying said one or more output signals in said first set of output signals.

CLPV:
means on said monitoring display indicator for indicating when such condition occurs.

CLPV:
a display panel; and

CLPV:
thrust indicator display means for directly displaying the value of said calculated actual thrust on said display panel.

CLPV:
thrust indicator display means for directly displaying the value of said respective available, predicted, and actual thrusts.

CLPV:
a first computer means responsive to said determined operating conditions for calculating the actual thrust of said aircraft engine based on said determined conditions and generating an actual thrust output signal representative thereof;

CLPV:
said computer means including a second computer means responsive to said determined operating conditions for calculating the predicted and available thrust of a functional model of said aircraft engine under said determined operating conditions and generating signals representative of the values of said predicted and available thrusts: and

CLPV:
thrust indicator display means for simultaneously displaying the values of said actual, predicted, and available thrusts.

L11: Entry 1 of 7 File: USPT Mar 27, 2001

DOCUMENT-IDENTIFIER: US 6208955 B1
TITLE: Distributed maintenance system based on causal networks

ABPL:
The present invention relates to a diagnostic system for complex systems such as avionics systems. The diagnostic system acquires a description of the system from a variety of design tools and creates a causal network model as an intermediate step. From the causal network model, the diagnostic system builds and compiles a Q-DAG model of the system, which is then embedded in the central maintenance computer of the aircraft. The present invention integrates two elements, a graphical user interface (GUI), which acts as a data capture tool and graphical display of the avionics system and an inference system, which acts as a diagnostic tool with a presenter. The presenter permits diagnosis of faulty sub-systems and a report may be relayed to remotely located maintenance crews to minimize repair time upon arrival of the aircraft.

BSPR:
Explosive growth in technology has made possible increasingly complex avionics systems for use in aviation, missilery and astronautics. In particular, the development of electrical and electronic devices have ushered in an era where avionics systems now assist the flight crew in virtually every aspect of operating modern aircraft.

BSPR:
Reliable operation of the aircraft therefore depends on avionics systems that not only perform their intended functions but are also reliable. In operation, however, vibration, rapid attitude changes, rapid environmental changes and other similar influences can affect performance and reliability of the avionics system. By way of example, the avionics system may include electrical and electronic sub-systems having an intended use in communications, navigation, aircraft control, remote sensing (such as the amount of on-board fuel), wiring and power distribution, life support, electronic warfare equipment (in military aircraft and missilery) and various sensors that provide vital real-time information. Accordingly, those concerned with flying and maintaining the aircraft, in particular, require methods of verifying the correct operation of the avionics systems both in-flight and during maintenance periods. For this reason modem aircraft include a real-time diagnostic system to monitor the avionics and other systems.

BSPR:
Modern commercial aircraft (such as the Boeing 747 and the Boeing 777 models provided by the Boeing Company) include diagnostic systems based around a central maintenance computer (CMC). This system collects, processes and evaluates avionics system information to verify normal operation by comparing sensor inputs against pre-defined rules to detect operational failures.

BSPR:
For example, the diagnostic system on the Boeing 747-400 aircraft uses loosely structured Boolean logic equations to perform its diagnostic evaluation. The primary disadvantage of this diagnostic system stems from the complexity of the rules (i.e., logic equations) and the difficulties engineers have in maintaining the rules over the life of the aircraft. Another disadvantage suffered using this approach is that diagnostic accuracy is limited by lack of standards for the various sub-systems that comprise the avionics system and by lack of large-scale system simulation capability. Unfortunately, even though the implementation of the diagnostic system on the 747-400 took a significant amount of time and

expense to mature, its adaptation or implementation on other aircraft is not possible. Thus, this time and expense must be incurred for each type or model of aircraft. Further, upgrades or additions to the avionics system during the life of the aircraft often require additional expensive and time-consuming effort to update the model to reflect the changes to the diagnostic system.

BSPR:
To overcome the problems associated with the above-described diagnostic system, the Boeing 777 aircraft adopted a shallow model-based approach based on a simple relational database structure. This diagnostic system segments the primary diagnostic functions such as signal validation, cascade-effect removal and fault isolation and correlation into a series of sequentially processed tasks. This approach, however, is limited since the shallow low-fidelity model paradigm focuses on reporting faults rather than evaluating physical system-level failure characteristics. Further, this model-based approach does not easily support analysis of the complex relationships among fault signals.

BSPR:
Another shortcoming of the Boeing 777 diagnostic system is that it is text based. Thus, it offers very limited design or analysis capability and offers no simulation capability. Further still, this diagnostic system offers only limited fault coverage leading to large ambiguity groups and "no fault found" conditions for line replaceable units (LRUs) pulled from the aircraft during the repair effort.

BSPR:
If changes are made to the avionics systems, both of the diagnostic systems described above must regenerate an entirely new model or set of rules, an expensive and technically demanding process. Traditional avionics system diagnostic system architecture tightly couples diagnostic interfaces (such as graphic displays, control panels, sensor inputs, keyboards) data storage and retrieval, and the application code in a single black box. This architecture provides for a focused diagnostic system that meets the diagnostic requirements of one avionics system. However, such diagnostic systems are difficult to modify, expand or upgrade since it requires detailed knowledge of the entire avionics system. Further, the process of modifying the model or amending the rules to incorporate the changes to the avionics system is a non-trivial task that is time consuming, expensive and susceptible to error. Further still, such diagnostic systems do not provide any system level visibility of how sub-systems work together so it is difficult for pilots and ground crew to visualize the overall system and the inter-relationship of the various sub-systems. This lack of system level visibility makes trouble shooting unnecessarily complicated, expensive and time consuming.

BSPR:
Few current diagnostic systems provide the capability to model an avionics system on a system level incorporating the design of various sub-systems from many different manufacturers into a cohesive model. Further, no current diagnostic system provides the capability to perform detailed simulation and diagnostic testing of the avionics system to guarantee rapid generation of a rule set that fully defines all potential failure modes. Further still, no current diagnostic system provides real-time diagnostic inference of avionics system failure in a visual manner so that the inter-relationship between various sub-systems is readily apparent to both the flight crew and a ground based maintenance crew. Thus, whatever the merits of the above described prior art diagnostic systems for avionics systems, they do not achieve the benefits of the present invention. Clearly, what is needed is a diagnostic system for avionics systems that provides greater flexibility, expansion, and maintainability than prior art solutions. What is also needed is a user-friendly system for modeling the interaction of the various sub-systems comprising an avionics system and for diagnosing system failure modes based on this model. Further, since the available memory and diagnostic computing power is typically limited on board an aircraft, it is desirable that the diagnostic system consume a minimum of computer resources while at the same time providing full coverage of the potential failure modes of the avionics system.

BSPR:
The present invention relates to a diagnostic system for avionics systems. The diagnostic system is tailored to aircraft applications and has diagnostics,

evaluation and presentation capabilities linked by an Internet Inter-ORB protocol (IIOP) communication backbone. The diagnostic system comprises a distributed development system and an on-board evaluation system.

BSPR:
By defining normal and faulty behavior of the individual sub-systems, a diagnostic model is generated that provides a high degree of fault coverage while using a minimum of system resources. In the event of a fault in the avionics system, the present invention graphically identifies the subsystem and preferably the faulty line replaceable unit (LRU). The diagnostic system provides two levels of diagnostic reports if failures are detected. A first level error indicates that there is a serious failure that must be immediately forwarded to the flight deck. A second level error is retained in memory associated with the evaluation system and transmitted to the maintenance ground crew. In general, diagnostic information is transmitted to one or more presenters that graphically display a representation of the avionics system and diagnostic inference identifying the faulty LRU in the event of a fault. The presenters may be on-board the aircraft or ground-based in locations remote from the aircraft.

BSPR:
The present invention utilizes a distributed maintenance architecture based on open system standards to reduce costs for developing, upgrading and extending the onboard maintenance system. The present invention provides flexible reasoning methods, data collection and concentration mechanisms, on-board diagnostic reasoning, and a maintenance display platform. Additional benefits are improved responsiveness, throughput and extensibility. Using a distributed system allows for functions to reside on multiple computer platforms. The well-defined object interface allows loading on the computer resources unit to be shared over a network, as well as to dynamically change the distribution of tasks for better load sharing and redundancy management. Individual components of the avionics system can be upgraded without affecting the other components. Further, if necessary, additional functional objects can be added to the open system to allow for unplanned options to be incorporated with less risk and cost than previous maintenance systems could provide.

DEPR:
Referring to FIG. 1, a representative avionics system 100 is illustrated. Avionics system 100, as implemented on an aircraft, may include a central maintenance computer (CMC) 102, flight deck presenter 104 and a plurality of sub-systems 106. A system bus (or buses) 108 couples CMC 102 to sub-systems 106 and to flight deck presenter 104.

DEPR:
Presenter 104, in one embodiment, is a video display monitor capable of displaying text and graphical images in a variety of colors. Various peripheral devices, such as a printer and input devices, such as a keyboard or a mouse, may be associated with presenter 104. In addition to presenter 104, the flight deck includes a plurality of subsystem 106 including a flight computer, a variety of display units for displaying flight parameters, control devices for adjusting flight parameters, as well as various navigational and communication devices for use by the flight crew. Each instrument, display, control element and the flight computer may be paired with one or more redundant backup instruments, displays, control elements or computers to ensure safe operation of the aircraft in the event of failure during operation of the aircraft.

DEPR:
Sub-systems 106 also include, by way of example, sensors, communications, navigation, processors, controls, displays, instruments, antennas, electronic warfare equipment, interface devices, electronic data bases, power distribution support systems and devices. Other sub-systems 106 include engines, mechanical elements such as flaps, rudders, linkages, landing gear and the hydraulic system and any other sub-system that may be deemed desirable for inclusion on an aircraft. One familiar with aircraft operation will appreciate that each sub-system 106 will include a plurality of modular line replaceable units (LRUs). When a particular sub-system fails, the diagnostic system of the present invention will identify one or more LRUs most likely to have caused the failure condition. Thus, maintenance crews need only identify the faulty LRU and need not troubleshoot the failure to the component level.

DEPR:
CMC 102 receives state variables defining the operational state of the various sub-systems 106. CMC 102 may, in some embodiments, be part of the flight computer or tasked to perform other functions (such as navigation) rather than a computer processor dedicated to monitoring the operational state of sub-systems 106. As such, the diagnostic system of the present invention must be efficient in terms of CPU usage and memory requirements. CMC 102 includes a computer processor, program memory, input means for receiving operational or performance data from sub-systems 106 and input devices such as a keyboard and/or a mouse, a joystick (not shown). CMC 102 also preferably includes a magnetic or optical storage/retrieval device 110 such as disk drive or CD ROM drive and an on-board visual display unit 112 such as a liquid crystal display (LCD) or a video (CRT) display. In the preferred embodiment, display unit 112 displays both text and graphical information in color. In the illustrated embodiment, CMC 102 obtains real-time information from sensors (not shown) associated with each sub-system 106 and converts such information to state variables.

DEPR:
FIG. 2 illustrates, by way of example, one embodiment of a representative sub-system 106; specifically, a communication sub-system 200 such as may be implemented on an aircraft. In communication sub-system 200, antennas 204 receive and transmit radio frequency information to a plurality of specialized units, such as VHF receiver 206, VIR receiver 208 and navigational instruments DME 210 and TDR 212. These units 206-212 interface with radio tuning unit (tuner) 202 over a bus 214.

DEPR:
In operation, information from tuner 202 is transferred to units 206-212 to select transmission and reception frequencies and operation. At various times, units 206-212 transmit and/or receive information that is relayed to tuner 202 over bus 214. However, if an error is detected in communication sub-system 200 (for example, no information is being received on-board the aircraft), it could be manifested as a failure of tuner 202 or one of the units 206-212, by a short or open bus connection, by a loss of power, by loss of antennas 204 or by a combination of two or more of failures modes. As described more fully below, the embedded Q-DAG files provides the diagnostic inferences necessary to identify the source of the error and identify the LRU that should be replaced to restore operation.

DEPR:
This Q-DAG tree is then embedded in diagnostic evaluator 320. In one preferred embodiment, evaluator 320 is a diagnostic engine resident in the memory of CMC 102. Q-DAG evaluation is performed by CMC 102 in accordance with the process specified by evaluator 320. System state variables are obtained at inputs 316 and 318 and are passed in real time to evaluator 320. Evaluator 320 filters these inputs through the Q-DAG tree and generates a failure report listing possible faulty sub-systems, as shown at 322 and 324. The failure report is accessible at either display 112 or as an electronic report on storage/retrieval device 110 (FIG. 1) for access by ground crew during maintenance periods.

DEPR:
Since low-level real-time data flow (for example, current or voltage levels) through the LRUs, buses, wires or switch is not visible in diagnostic system 300, only fault reports and flight deck effects (FDEs) will be reported to CMC 102. CMC 102 has no knowledge about any specific monitor block or data value that triggered a fault report. Thus, the only conclusion when an apparent failure mode is detected is that a possible failure has occurred inside one of the LRUs or on a bus, wire or switch. It is an advantageous feature of the present invention that low-level real-time data need not be evaluated and need not be acquired by the diagnostic system.

DEPR:
The user has the option of running any script straight through from beginning to end or to walk through the simulation step by step. At each step of the simulation, activity state changes for all fault reports and flight deck effects (FDE) are indicated by color changes in the fault report or FDE primitives on a display device (not shown) associated with the off-line system of FIG. 3. Thus, it is possible to provide an animation of the process of instantiating faults and propagating faults throughout the system model as the simulation proceeds. The

user can select different views of the data such that in a "cascade" view all elements in a cascade chain are highlighted. Alternatively, an ambiguity group view can be selected such that all components in the current ambiguity group (i.e., a summary of all possible diagnostic explanations for the current state) are highlighted. By examining the connectivity between the components that make up this ambiguity group, an ambiguity group can be viewed as all failure sources, wires and buses that feed into a monitor block. Since this connectivity is included in the model, the model can be queried to indicate the next best test or position to execute or probe in order to reduce the ambiguity group. These tests can be defined for each component or failure. A cost based on time to test, cost to test, or some other parameter can be associated with every test so that the tests could be ranked by selected criteria such as least time or cost.

DEPR:
The diagnostic computation incorporates cascade effect removal, fault isolation, fault consolidation and FDE correlation into one consistent model, which are inherent properties of a causal network model. Once a model has been constructed, the diagnostic algorithms of CNETS automatically perform all of these functions in a single diagnostic process. It is also possible to highlight the portions of a model that relate to these functions. The causal network model approach integrates these tasks together rather than requiring sequential execution of the separate tasks such as required in prior art systems such as used with the Boeing 747-400 rule-based diagnostics and the Boeing 777 model-based diagnostics. This feature is extremely valuable for verifying model behavior and correctness.

DEPR:
This Q-DAG model is transferred to compiler 710. Diagnostic output is passed from compiler 710 to either display 112 (FIG. 1) and/or schematic capture and viewer system 704 for further simulation. The Q-DAG compiler 710 generates a set of table-loadable files (representing the Q-DAG model) to be transferred to real-time, on-board components of diagnostic system 800. These files are certified to comply with governmental or manufacturer specification for use on-board an aircraft.

DEPR:
Referring now to FIG. 8, one preferred embodiment of an embedded or on-board diagnostic system 800 is shown. More specifically, the diagnostic system 800 comprises three separate distributed components. A first component is a data collector 804 that is a front-end processor for monitoring bus activity on system bus 108 (see FIG. 1) and sampling the plurality of sensors associated with subsystems 106 (see FIG. 1). Data collector 804 performs filtering functions such as persistency or signal de-bouncing on the input data obtained from the system sensors. It also conditions analog sensor inputs providing corresponding discrete value outputs. Data collector 804 then passes state changes such as fault reports, FDEs, or other status information to a diagnostic engine or Q-DAG evaluator 320, the second component of system 800.

DEPR:
Table-loadable files (i.e., the compiled Q-DAG model) generated by diagnostic system 700 are passed to evaluator 320 over a communication link, indicated by dashed lines 803, such as Internet or a similar distributed network configuration. Evaluator 320 uses these Q-DAG files to evaluate sensor derived state variables provided by data collector 804 to determine if an error in the avionics system exists. If an error is detected, the state variables are filtered through evaluator 320 to generate a diagnostic inference or conclusion as to the source of the error. Evaluator 320 also updates the compiled Q-DAG model based on the state changes obtained from data collector 804 and generates a diagnostic report of the current state of avionics system 100 on a either a continuous or periodic basis. Based on the results obtained by evaluator 320, the avionics system model is displayed on the third component, presenter 104 or remote presenter 810. Since table-loadable presentation views (i.e., schematic data) are passed to the presenter 104 and presenter 810 from diagnostic system 700, the presenters display a graphical representation of the system. When presenter 104 and presenter 810 receive results from evaluator 320, the hierarchical system level schematic description of avionics system 100 graphically correlates failure combinations or ambiguity groups with sub-systems 106 or specific LRUs. If an error has been detected, the presenters show the error source as determined by evaluator 320 together with the cascade effect such error will have throughout the avionics system. These results may be communicated, either automatically or

on demand, to presenter 104 and/or presenter 810. The presenters display the ambiguity group(s) or possible failure combinations, if any, to the user or more specifically the flight or maintenance crew. This distributed environment allows for multiple data collectors 804, evaluators 320, presenters 104 and/or remote presenters 810. These components communicate over a network communication means 808, such as an Ethernet network using the CORBA/IIOP interface.

DEPR:
The distributed diagnostic system shown in FIG. 8 further includes an interface 812 that provides a satellite link for data telemetry to remote presenter 810. Interface 812 connects presenter 810 to the on-board system. Interface 812 provides a viewer at a remote location the ability to monitor the state of the avionics system in real time. Advantageously, this interface 812 enables the remote presenter 810 to diagnosis faulty sub-systems at a ground-based facility while the aircraft is still in the air. Based on the diagnoses, remotely located maintenance crews may minimize repair time upon arrival of the aircraft by having replacement LRUs available.

DEPL:
specific LRU enables viewing of the monitors and generators attached to corresponding ports of the LRU. These monitors and generators are in turn connected to specific buses or wires at the system level. Deeper levels may be viewed by selecting the ports or monitors to display the receivers, transmitters and associated failure sources or the components that make up the monitor as described above.

DETL:
TABLE 1 Wire: If wire is OK, & input (i) is active Then output (o) is active. If wire is OK & i is inactive Then o is inactive. If wire is faulty Then o is active. ##STR1## Bus: If bus is OK, & i is active Then o is active. If wire is OK & i is inactive Then o is inactive. If wire is faulty Then o is inactive. ##STR2## Data integrity Receiver & Transmitter: If failure input (f) is inactive & input (i2) is active Then o is active. If f is inactive & i2 is inactive Then o is inactive. If f is active & i2 is active Then o is inactive. If f is active & i2 is inactive Then o is active. ##STR3## Bus Activity If failure (f) is inactive & input (i2) is active Then o is Note: Receiver and inactive. Receiver Transmitter: If f is inactive & i2 is inactive Then o is active. followed If f is active & i2 is active Then o is active. by If f is active & i2 is inactive Then o is inactive. inverter Failure source: If no failure Then o is inactive If failure Then o is active ##STR4## CMC fault report If communication path is OK & i is active Then o is active. If communication path is OK & i is inactive Then o is inactive. If communication path is faulty Then o is no data. ##STR5## FDE: If i & o are active Then FDE is correlated. ##STR6## AND gate: If all inputs (i1 and i2) are active Then o is active If i1 or i2 is inactive Then o is inactive ##STR7## OR gate: If i1 or i2 is active Then o is active If i1 or i2 are inactive Then o is inactive ##STR8## NOT gate (inverter): If i is active Then o is inactive If i is inactive Then o is active ##STR9## XOR gate: If i1 and i2 is are the same (active or inactive) Then o is inactive If i1 and i2 are not the same Then o is active ##STR10##

CLPR:
29. The diagnostic system of claim 28 wherein said display means comprises a graphical viewer, coupled to said communication network, for developing hierarchical models and for providing a graphical interface between system models generated by said schematic capture and said inference means.

CLPV:
a CORBA interface, associated with said model building means, said database, said acquiring means and said display means, for brokering and communicating objects over said communications network.

CLPV:
monitoring observable variables of said avionics system in accordance with said compiled Q-DAG representation to correlate said observable variables with flight deck effects; and

CLPV:
generating a graphical display, on said viewer, of said combined diagnostic inference and said electro-mechanical system.

L11: Entry 4 of 7 File: USPT Aug 29, 2000

DOCUMENT-IDENTIFIER: US 6112140 A
TITLE: Flight management system providing for automatic control display unit backup utilizing structured data routing

ABPL:
An improved aircraft flight management system includes a flight management computer (FMC), left and right control display units (CDU's) and a backup CDU. A triple redundant digital databus links the FMC and three CDU's. Upon detecting a failure in either the left or right CDU, the FMC utilizes reconfiguration rules stored in a look-up table to automatically cause the backup CDU to replace the failed CDU in operation, thereby relieving the flight crew of the burden of interfacing to the FMC through only one CDU. Upon detection of a failed databus, the system similarly utilizes structured data routing to reconfigure around the failed databuses. In addition, if any two CDU's have failed in a three CDU system, automatic data rerouting is implemented to the non-failed CDU to insure FMC to CDU communication.

BSPR:
The present invention relates to the aircraft flight management art and, in particular, to an improved flight management system comprising redundant control display units (CDU's), redundant databuses and a flight management computer (FMC), which automatically responds to detected failures in CDU's or databuses to maintain an operating FMC-CDU interface.

BSPR:
In modern commercial aircraft, a flight crew makes flight plan entries and modifications through a Flight Management System comprising one or more flight management computers (FMC's) and, typically, left and right control display units (CDU's). The FMC's and CDU's are linked by redundant databuses. These CDU's are positioned to be accessed by the pilots for purposes of flight plan data entries into the CDU's and then to the FMC's for implementation of a desired flight plan.

BSPR:
In some aircraft, a third CDU unit has been provided in the flight deck. However, such CDU's are provided to perform functions other than FMC interface. In the event that one of the primary left or right CDU's has failed, this leaves only one CDU remaining for the flight crew to perform FMC operations. Only one operating CDU results in reduced crew capability for dealing with flight management functions even though an additional CDU might be physically on board. Thus, loss of a CDU creates increasing work load for the pilot which has the remaining functional CDU. A second fault in a CDU or associated databus could result in the total loss of CDU control.

BSPR:
It is an object of this invention, therefore, to provide an improved aircraft flight management system which, upon detection of a failed control display unit or databus, automatically reroutes the data to maintain an operating CDU.

BSPR:
Briefly, according to the invention, an improvement is provided in an aircraft flight management system which includes at least one flight management computer (FMC), at least two control display units (CDU's) and at least two databuses permitting interfaces to the said at least one FMC from said CDU's. The improvement comprises logic control which is associated with the FMC. The logic control includes means for detecting the failure of one of said CDU's and/or

databuses and, in response thereto, utilizing structured data routing to reroute signals over a non-failed databus to connect a non-failed CDU to the FMC.

BSPR:
In an aircraft flight management system which includes at least one flight management computer (FMC) left and right control display units (CDU's) permitting interfaces to the FMC from left and right pilot positions, respectively, and a third, backup CDU, an improved method for improving the backup CDU to automatically function in place of a failed left or right CDU comprises the steps of:

DRPR:
FIG. 1 is a diagram illustrating the general appearance and relative interconnection of the flight management system including the control display unit (CDU), databuses, navigation display (MAP) and logic module;

DRPR:
FIG. 2 depicts an aircraft main instrument panel and its interconnecting relationship to the flight management computers, autopilot flight director system, flight control computers, interconnecting digital databuses and the three CDU's;

DEPR:
FIG. 1 illustrates in both graphic and block diagram form the primary components of a modern commercial flight management system, indicated generally at 30. Shown at 32 is a conventional aircraft navigational Flight Management System-Control Display Unit (FMS-CDU). The FMS-CDU 32 includes an upper face portion 34 and a lower face portion 36. In its upper face portion 34, the FMS-CDU 32 includes an electronic display 40 which is capable of displaying lines of text entered by the flight crew. These lines of text depict, typically, waypoints along the path of a desired navigational route. On both sides of and adjacent to the electronic display 40 are line select keys, indicated generally at 42 and 44. Upon the user activating one of the line select keys 42, 44, the adjacent line of text on the electronic display is activated to thereby allow entry, selection or deletion of text.

DEPR:
At the lower portion of the electronic display is scratch pad line 46 which displays system generated messages, entries via the keyboard (described below) and data being moved from one line to another.

DEPR:
In the lower face half 36 of the FMS-CDU 32 is a keyboard, indicated generally at 50. The keyboard 50 includes an array of keys as well as control inputs by which the flight crew can manually enter waypoints, which then appear on the electronic display 40 as text line items. Also included are various control keys which allow the flight crew to add, modify, and delete various entries.

DEPR:
A provided Delete key 54 is a momentary action switch which, when activated by the flight crew, enters DELETE in the scratch pad portion 46 of the electronic display 40. When the scratch pad is blank, a selection of a subsequent line by line select keys 42, 44 deletes data on the corresponding adjacent line if such information is deletable.

DEPR:
Thus, by way of typed entries via the keypad 50, the flight crew enters waypoints along the desired navigational route. These waypoints are displayed as lines of text on the electronic display 40.

DEPR:
Also provided as a display to the flight crew of the desired navigational route is a navigational display (MAP) 60. The navigation display 60 depicts the current position of the aircraft, herein indicated by the triangle 62, at selected waypoints along the desired route such as the indicated waypoint "VAMPS" at 64, the next selected waypoint "RUMOR" at 66 and the final waypoint "ELN" at 67.

DEPR:
In addition to the route information also depicted on the navigation display 60

is the current magnetic track heading 68 and an arcuate line 70 which depicts a portion of a compass rose.

DEPR:
Also depicted in the upper left hand corner of the display 60 is information indicating the current ground speed, true air speed, wind speed and wind heading information, collectively shown at 72.

DEPR:
The navigation display 60 and FMS-CDU 32 interconnect through a logic module indicated generally at 80. The logic module 80 includes the flight management computer (FMC) 82. In addition, the logic includes the graphics generator (display module) 84. Inputs from the logic module 80 to and from the FMS-CDU 32 are carried along a multi-way bus 86, whereas display information from the graphics generator 84 is carried to the navigation display 60 via a one-way bus 88.

DEPR:
The flight management computer 82 provides lateral (LNAV) and vertical (VNAV) guidance signals to the autopilot flight director system (AFDS) 83, which validates and acknowledges the guidance signals. The AFDS 83 then provides guidance signals to the Primary Flight Computer (PFC) 87 which activates the aircraft's control surfaces 85 in the normal manner such that the aircraft is directed to automatically fly the route as selected by the flight management computer 62.

DEPR:
FIG. 2 illustrates a typical navigation arrangement as found in a modern commercial aircraft. Shown are left and right flight management computers (FMC's) 102, 104, respectively. The left and right FMC's 102, 104 communicate with associated left and right control display units (CDU's) 112, 114, respectively. The left and right CDU's 112, 114 are arranged for easy access by the pilots. As is often provided in modern commercial aircraft, a third, backup, or center channel CDU 120 is also provided. The third CDU 120 is used in some aircraft to interface to other aircraft systems such as satellite communications, SATCOM, and/or the public address/cabin interphone system (PACI).

DEPR:
In normal operation, one of the two FMC's 102, 104 assumes primary control, here identified as left FMC 102. Thus, outputs from FMC 102 are provided both to the main instrument panel 140 and to an autopilot flight director system 150. The main instrument panel 140 includes left and right primary flight displays 142, 144, which are driven by left and right outputs from the autopilot flight director system 150. Left and right navigation displays 146, 148, respectively are driven by corresponding outputs from the primary FMC 102. A central engine and crew altering display 149 is also provided in the main instrument panel 140.

DEPR:
In the manner described with respect to FIG. 1, flight crew entries into the left and right CDU's 112, 114 of desired flight plans are then transferred to the FMC's 102, 104, with corresponding graphical depiction of the flight plans set forth on the left and right navigation displays 146, 148.

DEPR:
The autopilot flight director system 150 then produces corresponding output signals which pass to the primary flight computers 160. The primary flight computers 160, in turn, produce appropriate control signals which are applied to the aircraft's flight control surfaces 170 to cause the aircraft to fly in accordance with the flight crew entered flight plan in the CDU's 112, 114.

DEPR:
If, out of decision block 202, the FMC logic determines that the left CDU is operating properly, block 204 is entered. In block 204, the FMC logic directs that the left page of the CDU display be sent to the properly operating, left CDU.

DEPR:
If, out of decision block 206, it is determined that the right CDU is operating properly, the system then enters block 210. In block 21, the FMC logic causes the

right page display to be sent to the right CDU. The system then reverts to 212 causing the logic to begin again at the begin stage 200.

DEPR:
not operating properly, decision block 220 is entered. At decision block 220, the FMC logic determines whether the center, or backup CDU (120 in FIG. 2) is operating properly. If the backup CDU is operating properly, the logic enters block 222. At block 222, the FMC logic now causes the left page display to be sent to the center, or backup CDU. As such, the backup CDU can now function in place of the failed CDU.

DEPR:
At decision block 224, the FMC logic determines whether or not the right CDU is functioning properly. If the right CDU is functioning properly, the logic enters block 210 and the right page display is then sent to the right CDU, with the system returning to the begin function 200 through intermediate step 212.

DEPR:
If, however, out of decision block 230 it is determined that the center CDU is operating properly, block 232 is entered. In block 232, the FMC logic causes the right page display to be sent to the center CDU, thereby causing the center CDU to assume the functionality of the failed right CDU. The system then returns to the begin point 200 through intermediate position 212.

DEPR:
FIG. 4 is a logic flow diagram depicting the sequence of logical steps performed by the improved flight management system to reconfigure the databus pathways to the operating control display units.

DEPR:
The CDU's are required to maintain a periodic message over all three databuses to allow the FMC to determine allowable data paths. The column labeled Previous CDU.sub.-- C indicates if CDU.sub.-- C was last selected for the Capt CDU Display (C), FO CDU Display (F), or if the previous CDU.sub.-- C is a Don't Care (X). If CDU.sub.-- C was previously not selected and the state depends on the previous CDU.sub.-- C selected, then Capt CDU Display shall be assumed.

DEPR:
The right-most columns indicate the target CDU (LC=CDU.sub.-- L, CC=CDU.sub.-- C, RC=CDU.sub.-- R) and bus path (LB, CB, RB defined same as above) to be used for each of the Capt (Captain) and FO (First Officer) CDU Displays. The nomenclature--indicates that the CDU display is not available on any of the CDU's.

DEPR:
3. The selected set of CDU's should minimize the flight deck effect of failures.

DEPR:
To support the analysis of the third criteria above, the table of FIG. 6 summarizes CDU transitions which can occur as the result of a single failure using the reconfiguration rules set forth in the FIGS. 5A, 5B and 5C table and helps to illustrate the resultant flight deck effects. Although many reconfigurations may occur in the FIGS. 5A, 5B and 5C table, following the above three criteria, a flight deck effect will only occur when a transition in CDU interface to the FMC is generated. The transitions are listed as "12.fwdarw.34" where "1" indicates which CDU the Capt (Captain) was using, "3" which CDU is provided to the Captain as a result of the transition, "2" which CDU the FO (First Officer) was using, and "4" which CDU is provided to the FO as a result of the transition. Following each transition state, is a list of up to the first eight reconfiguration rule pairs (from the table of FIGS. 5A, 5B and 5C) which, when exercised, will result in the appearance of the transition (flight deck effect) identified in the left column. Where more than 8 rule pairs can cause an affect, `. . .` is listed. Note that the ordering of the rule pairs does not necessarily correspond to the order of the transition.

DEPR:
In summary, an improved aircraft flight management system has been described in detail. The improved system is capable of detecting failure of either the left or right control display unit to automatically activate a backup control display

unit to assume the functionality of the failed unit. In addition, the system can detect and reconfigure around one or more failed databus(es).

CLPR:
1. In an aircraft flight management system including at least one flight management computer (FMC), at least two control display units (CDU's) and at least two databuses permitting interfaces to said CDU's from said FMC, the improvement comprising:

CLPR:
2. The improvement of claim 1 wherein the aircraft flight management system includes a second FMC and said logic control means predetermined look-up table includes a hierarchy of reconfiguration scenarios based on the possible failures of the CDU's, databuses or FMC's.

CLPR:
3. An aircraft flight management system comprising:

CLPR:
4. The system of claim 3 wherein the aircraft flight management system includes a second FMC and said logic control means predetermined look-up table includes a hierarchy of reconfiguration scenarios based on the possible failures of the CDU's, databuses or FMC's.

CLPR:
5. In an aircraft flight management system including at least one flight management computer (FMC), left and right control display units (CDU's) permitting interfaces to said at least one FMC from left and right pilot positions over two or more databuses, an improved method for automatically rerouting signals between the FMC and a non-failed CDU over a non-failed databus, the method comprising the steps of:

CLPR:
6. The improvement of claim 5 wherein the aircraft flight management system includes a second FMC and said logic control means predetermined look-up table includes a hierarchy of reconfiguration scenarios based on the possible failures of the CDU's, databuses or FMC's.

CLPR:
7. In an aircraft flight management system including at least one flight management computer (FMC), left and right control display units (CDU's) permitting interfaces to said at least one FMC from left and right pilot positions over multiple, redundant databuses respectively, the improvement comprising:

CLPR:
8. The improvement of claim 7 wherein the aircraft flight management system includes a second FMC and said logic control means predetermined look-up table includes a hierarchy of reconfiguration scenarios based on the possible failures of the CDU's, databuses or FMC's.

CLPR:
9. An aircraft flight management system comprising:

CLPR:
10. The system of claim 9 wherein the aircraft flight management system includes a second FMC and said logic control means predetermined look-up table includes a hierarchy of reconfiguration scenarios based on the possible failures of the CDU's, databuses or FMC's.

CLPR:
11. In an aircraft flight management system including at least one flight management computer (FMC), left and right control display units (CDU's) permitting interfaces over multiple, redundant databuses to said at least one FMC from left and right pilot positions, respectively, and a third, backup CDU, an improved method for permitting said backup CDU to automatically function in place of a failed left or right CDU or databus, the method comprising the steps of:

CLPR:

12. The improvement of claim 11 wherein the aircraft flight management system includes a second FMC and said logic control means predetermined look-up table includes a hierarchy of reconfiguration scenarios based on the possible failures of the CDU's, databuses or FMC's.

CLPV:
left and right control display units (CDU's) permitting interfaces to said at least one FMC from left and right pilot positions, respectively;

CLPW:
left and right control display units (CDU's) permitting interfaces to said at least one FMC from left and right pilot positions, respectively;

ORPL:
IEEE/AIAA 10.sup.th Digital Avionics Systems Conference, Oct. 14, 1991, pp. 482-486, XP000309289 H. Griguere: "Flight Management System Back-p Navigation for the A330/A340 Aircraft".

ORPL:
Scientific Honeyweller, vol. 11, No. 1, 1991, pp. 57-70, XP000289742, K. Hoyme et al.: "ARINC 629 and SAFEbus: Data Buses for Commercial Aircraft".

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L17: Entry 8 of 11 File: USPT Jun 23, 1987

DOCUMENT-IDENTIFIER: US 4675675 A
TITLE: Automatic fault reporting system

ABPR:
Phase I (25) and Phase II (20) and III (24) AFRS (Automatic Fault Reporting System) signal processing implementations (FIG. 3) of fault related data permits utilization in steps, viz. Phase I and Phases II and III on board operational aircraft of AFRS, thereby permitting gradual phase in and substitution of AFRS for present state of the art flight crew FRM (Fault Reporting Manual) and ground personnel FIM (Fault Isolation Manual).

BSPR:
This invention relates to fault reporting and, more particularly, to an aircraft maintenance scheduling system by which fault-related data onboard an operational aircraft is processed through a communications channel to a ground terminal.

BSPR:
Heretofore, the patent literature, e.g. U.S. Pat. No. 3,689,888, has shown a pulse-position modulated alarm system having automatic fault detection and utilizing radio transmission channels. This system, however, did not relate to maintenance or aircraft fault detection nor provide for scheduling of maintenance.

BSPR:
U.S. Pat. No. 3,242,321 discloses an automatic machine analyzer which does demonstrate maintenance and automatic fault detection but fails to show an aircraft application or the scheduling of maintenance, or the utilization of radio transmissions of data.

BSPR:
U.S. Pat. No. 3,720,911 is illustrative of motor vehicle identification and speed control systems which provide for maintenance, utilize radio transmission, and relate to scheduling of maintenance; however, this patent does not show aircraft applications or automatic fault detection.

BSPR:
A further monitoring system specifically for construction vehicles is shown in U.S. Pat. No. 4,119,943. This patent shows automatic fault detection, radio transmission, and scheduling of maintenance but fails to relate to aircraft fault problems or transmission and signal processing of such type data.

BSPR:
U.S. Pat. No. 4,239,454 shows a system for monitoring bearings and other rotating equipment and does relate to maintenance and maintenance scheduling, radio transmission, and automatic fault detection, but has no bearing upon aircraft maintenance or fault detection problems.

BSPR:
A plant maintenance control system is shown in U.S. Pat. No. 4,383,298. Radio transmission of data, automatic fault detection, and aircraft applications are not shown in this patent system.

BSPR:
U.S.S.R. Pat No. 637,823 relates to aircraft servicing monitoring units and does disclose aircraft maintenance and maintenance scheduling but fails to disclose automatic fault detection or radio transmission of information in this regard.

BSPR:
Japanese Pat. No. 57-77335 discloses a remote-controlled monitoring system for construction vehicles. It appears to be quite similar in concept to the aforementioned system for monitoring construction vehicles shown in U.S. Pat. No. 4,119,943. The Japanese Pat. No. 57-77335 system does relate to automatic fault detection, radio transmission, and maintenance and maintenance scheduling design but fails to relate to aircraft applications and fault detection of onboard data.

BSPR:
Further literature relating to maintenance and scheduling of maintenance of machines does not appear to relate to the problems of fault detection and aircraft and automatic signal processing through radio transmission channels.

BSPR:
Present solutions to maintenance include providing flight crews of aircraft with FRM (Fault Reporting Manual, or equivalent). The FRM contains possible fault indications. The user is lead through logic tree formatted pages containing yes/no type questions. The end result of a fault analysis is an eight digit code which represents a specific fault condition. The user then radios this code to the ground and/or records it in the flight's log book.

BSPR:
On the ground, the maintenance personnel apply the fault code to the FIM (Fault Isolation Manual, or equivalent) which further isolates the fault. At this point, if the exact cause of the fault is not known, the maintenance personnel are given a general idea of what the cause(s) of the problem is and what maintenance action(s) will be required when the airplane arrives, thereby tending to minimize the possibility of a delayed or grounded flight.

BSPR:
The FRM is bulky and difficult to use. EX: Present FRMs are somewhat large and total approximately 600 81/2.times.11 inch pages. The book is divided by Airline Transport Association (ATA) chapter. Each chapter contains a pictorial contents, an alphabetic contents, and the fault code diagrams (which make up approximately 4/5 of the manual). The fault code diagrams (logic trees) contain an average of 5 to 10 fault codes each. There are roughly 2500 fault codes in each airplane copy. On short flights a flight crew may wait until the flight has landed and is taxiing to the terminal before using the FRM. This creates two problems: viz. (1) The crew may not have seen or remembered all conditions, actions, and indications when the fault occurred, thus creating an unreliable fault code; and (2) the fault codes are designed to be radioed in the air in order to allow the maintenance personnel time for part procurement, planning, etc. If the fault is of an intermittent type, a future failure may be indicated. If the fault is too quickly gone, the flight crew will likely not see all indications, if any at all.

BSPV:
(d) a "send data" discrete signal is awaited from the aircraft's onboard FMC (Flight Management Computer);

BSPV:
(e) on command, a "data present" discrete signal is sent to the aircraft's onboard ARINC Communications Addressing and Reporting System (ACARS) and a "transmission available" discrete signal is awaited;

DRPR:
FIG. 3 is a system block diagram showing aircraft installation of the present AFRS wherein the Phase I, Phase II, and Phase III aspects of the installation are detailed to facilitate an understanding of system operation and also how the present system concept may be adapted in steps, and wherein these modifications are shown in dotted line representation;

DEPR:
The Phase II and III Automatic Fault Reporting System (AFRS) (FIG. 1) is an all solid-state rack mounted unit that monitors and compares the data outputs of various airplane systems (depending on phase). The AFRS provides fault outputs when data presence, validity, or tolerance errors are detected.

DEPR:
The AFRS provides automatic comparing/monitoring of various aircraft data parameters during flight, and supplies fault outputs when failures are detected to the ACARS for transmission to ground-based maintenance operations. This AFRS system is one to be installed on airplanes and used in conjunction with presently installed airplane systems with the objective of reporting airplane system fault conditions prior to landing. The system would be completely automatic, thus relieving the flight crew from the responsibility of isolating and reporting BITE detectable fault conditions during flight. In addition, the information received by ground maintenance personnel will be much more exact, allowing more time for parts acquisition and the scheduling of maintenance personnel. Depending on how the information is used on the ground and the individual capabilities of each airline, this information can be fed into their main computer and used to assist in inventory control, airplane scheduling, flight crew scheduling, passenger scheduling, periodic maintenance scheduling, etc. The primary objective of the present AFRS system, however, is that of automatic airplane fault reporting. The functional responsibilities of the system are as follows (See FIG. 1):

DEPR:
The unit consists of an aluminum chassis with attached front panel and top plate, removable circuit cards, and a one-piece dust cover. The front panel contains a swing-out handle for ease of installation/removal, and two push-button switches (SELF TEST and DATA DUMP) located on the upper portion of the panel, as seen in FIG. 2. Cooling air inlet holes are located on the bottom of the unit with outlet holes located on the top of the unit. The importance of this system is the automatic reporting of presently available on-airplane fault information to the individual airline by using presently installed systems for the detection of faults and the unique transmission of the fault data. The unique control and processing of the data on the airplane will require a new box (i.e. AFRS) (10).

DEPR:
The Phase II and III AFRS monitors and compares the ARINC 429 low-speed outputs of various airplane systems (depending on phase--see FIG. 3). The AFRS provides outputs for transmission by ACARS whenever a difference between monitored system outputs exceed a predetermined value, and/or a warning flag condition is detected.

DEPR:
The internal circuits monitor and compare the low-speed ARINC 429 outputs of the applicable airplane systems based on discrete inputs. The monitoring and comparison functions result in the transmission to ACARS of parameter warnings via discrete and serial outputs.

DEPR:
The Phase II and III AFRS monitor and compares outputs from various aircraft electronic units. Failure outputs are provided to the ACARS whenever faults or excessive differences are detected between monitored inputs.

DEPR:
Due to the potential change impact on present airplane installations, the system can be installed in three phases (Phases I, II, and III). The first phase will only be software changes to the MCDP and two new ARINC data buses (25) when the MCDP (22) and the ACARS (13). This will be used to prove the concept and will provide all autopilot (FCC (17), FMC (12), TMC (9)) fault data to the ground via ACARS (13) and ARINC/SITA (10). The second phase will require the new AFRS box (10) (hardware) which will basically be a data management computer. This will also require new wiring (20) from the DFDAU (9) inputs (21) and reprogramming of some of the inputting systems. Phase II will provide fault data from a majority of the Navigation and Warning Systems (2). Phase III will include the fault data from every system on the airplane (23). This phase is presently considered as a future evolvement of the system due to extensive wiring (24) and software changes which will be required to presently installed system. The AFRS (10), however, will be designed to accommodate this future expansion capability. In conclusion, for present airplanes (i.e. 757/767), the present plan is to proceed through Phase II in order to provide the greatest amount of fault data while requiring the least amount of change to the airplane.

DEPR:

Digital inputs to the AFRS are received from the system listed in Table II (by phase) via ARINC 429 low-speed data buses. Also, analog and discrete inputs are received via standard airplane wiring. Each phase will include the information received by the previous phase(s). The digital inputs are monitored for signal presence and validity. Input discretes from various equipment are received via program pin selections in the aircraft wiring. Failure outputs are provided if data inputs are not present, not valid, or excessive differences are detected between monitored inputs.

DEPR:
The power supply converts the 115 V AC, 400 Hz aircraft power to +5, +5 KA, +12, and -12 V DC power required for AFRS operation. The +5 KA is a keep-alive voltage applied to the RAM to maintain memory during power switching or transients. The +5, +12, and -12 V outputs are short circuit protected by regulator/limiter/shutdown circuits. Monitor circuits will inhibit the AFRS and cause an AFRS fault warn output if the power supply voltages are not correct.

DEPR:
Note: Due to system and system output redundancy, cross channel checks are used to isolate faults between wiring or box problems. Also, due to redundancy and the vast number of systems and wiring, it is impossible to illustrate the entire airplane's systems.

DEPR:
g. On the ground, the operator will use this information to aid his maintenance scheduling, parts acquisition, and control flight crew and passenger rescheduling (if required) and any other application desired to reduce airplane turnaround time.

DEPU:
ACARS--(ARINC Communications Addressing and Reporting System) System presently installed on many airplanes at operator's option. Used for two-way digital communications from airplane to ground station via ARINC communications network.

DEPU:
ARINC--(Aeronautical Radio Inc.) North American organization which, among other services, provides a ground-based digital air/ground communications network for subscribing airplane operators and standards for airplane design.

DEPU:
BITE--(Built In Test Equipment) Monitoring circuits, on a system level, which periodically check the operation of that system. In the event of a failure, a signal is sent to display a flag and/or store the fault in that system's or another system's memory for maintenance referral.

DEPU:
FIM--(Fault Isolation Manual) Aircraft manufacturing company, e.g. Boeing Airplane Company prepared manual presently used by operator's ground personnel on airplanes. The manual is used to decode the fault codes transmitted by the flight crews and to determine the corrective maintenance actions required when the airplane arrives.

DEPU:
AFRS--(Automatic Fault Reporting System) System of fault reporting which also replaces presently used FRM type manuals and portions of presently used FIM type manuals.

DEPU:
SITA--(Societie Internationale de Telecommunications Aeronautiques) European equivalent of ARINC which will soon provide a worldwide ground-based digital air/ground communication network for subscribing airplane operators.

DEPU:
DFDAU--(Digital Flight Data Acquisition Unit) System used to acquire real time airplane data, format it per airline requests, and provide selectable output to the flight recorders.

DEPU:
ADC--(Air Data Computer) Senses environmental conditions around the airplane

(i.e. airspeed, altitude, etc.) from data provided by pitot static system.

DEPU:
IRS--(Inertial Reference System) System which senses airplane movement and is used to calculate altitude, position, speed, etc. for navigation purposes.

DEPU:
DME--(Distance Measuring Equipment) Provides radio distance from airplane to ground-based DME stations.

DEPU:
ILS--(Instrument Landing System) Radio navigation aid system used to guide airplane to runway during landings.

DEPU:
RA--(Radio Altimeter) Provides radio distance from airplane to ground.

DEPU:
WXR--(Weather Radar) Provides pictorial presentation of weather patterns ahead of the airplane.

DEPU:
PSEU--(Proximity Switch Electronics Unit) Monitors airplane proximity switch logic.

DEPU:
BPCU--(Bus Power Control Unit) Controls aircraft electrical power distribution.

DEPU:
MCDP--(Maintenance Control Display Panel) System used to isolate and display autopilot faults on ground only.

DEPV:
(7) When the FMC commands AFRS to send data, the AFRS will poll ACARS for transmission time. If the line is not busy, ACARS will transmit the data to an ARINC/SITA ground station via the airplane's VHF communications system. ARINC/SITA, in turn, will transmit the data to the correct operator via land lines.

CLPR:
1. In combination in an automatic fault reporting system for aircraft having left, right, and center channel inertial reference systems:

CLPV:
an aircraft very high frequency communications system;

CLPV:
said flight management computer commanding said means for storing said fail discrete signal representative of an internal fault in one of said left, right, or center channel inertial reference systems for transmitting said fail discrete signal representative of an internal fault in one of said left, right, or center channel inertial reference systems through said aircraft very high frequency communications system to said ground station.

ORPL:
Batten, "The Use of Computer Testing," Aircraft Engineering, vol. 47, No. 6 (1975).

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L17: Entry 7 of 11 File: USPT Nov 29, 1988

DOCUMENT-IDENTIFIER: US 4788531 A
TITLE: Automatic fault reporting system

ABPL:
An aircraft automatic fault reporting system having a plurality of ARINC 429 low-speed data buses between the aircraft maintenance control panel and the aircraft communications addressing and reporting system provides two-way communication therebetween. Detected faults through an eight-digit fault code are by means of a transient logic circuit under certain conditions of the aircraft communications and addressing systems provided to maintenance personnel thereby eliminating flight crew use of FRM's.

BSPR:
This invention relates to fault reporting and, more particularly, to an aircraft maintenance scheduling system by which fault-related data onboard an operational aircraft is processed through a communications channel to a ground terminal.

BSPR:
Heretofore, the patent literature, e.g. U.S. Pat. No. 3,689,888, has shown a pulse-position modulated alarm system having automatic fault detection and utilizing radio transmission channels. This system, however, did not relate to maintenance or aircraft fault detection nor provide for scheduling of maintenance.

BSPR:
U.S. Pat. No. 3,242,321 discloses an automatic machine analyzer which does demonstrate maintenance and automatic fault detection but fails to show an aircraft application or the scheduling of maintenance, or the utilization of radio transmissions of data.

BSPR:
U.S. Pat. No. 3,720,911 is illustrative of motor vehicle identification and speed control systems which provide for maintenance, utilize radio transmission, and relate to scheduling of maintenance; however, this patent does not show aircraft applications or automatic fault detection.

BSPR:
A further monitoring system specifically for construction vehicles is shown in U.S. Pat. No. 4,119,943. This patent shows automatic fault detection, radio transmission, and scheduling of maintenance but fails to relate to aircraft fault problems or transmission and signal processing of such type data.

BSPR:
U.S. Pat. No. 4,239,454 shows a system for monitoring bearings and other rotating equipment and does relate to maintenance and maintenance scheduling radio transmission, and automatic fault detection, but has no bearing upon aircraft maintenance of fault detection problems.

BSPR:
A plant maintenance control system is shown in U.S. Pat. No. 4,383,298. Radio transmission of data, automatic fault detection, and aircraft applications are not shown in this patent system.

BSPR:
U.S.S.R. Pat. No. 637,823 relates to aircraft servicing monitoring units and does disclose aircraft maintenance and maintenance scheduling but fails to disclose

automatic fault detection or radio transmission of information in this regard.

BSPR:
Japanese Patent No. 57-77335 discloses a remote-controlled monitoring system for construction vehicles. It appears to be quite similar in concept to the aforementioned system for monitoring construction vehicles shown in U.S. Pat. No. 4,119,943. The Japanese Patent No. 57-77335 system does relate to automatic fault detection, radio transmission, and maintenance and maintenance scheduling design but fails to relate to aircraft applications and fault detection of onboard data.

BSPR:
Further literature relating to maintenance and scheduling of maintenance of machines does not appear to relate to the problems of fault detection and aircraft and automatic signal processing through radio transmission channels.

BSPR:
Present solutions to maintenance include providing flight crews of aircraft with FRM (Fault Reporting Manual, of equivalent). The FRM contains possible fault indications. The user is lead through logic tree formatted pages containing yes/no type questions. The end result of a fault analysis is an eight digit code which represents a specific fault condition. The user then radios this code to the ground and/or records it in the flight's log book.

BSPR:
On the ground, the maintenance personnel apply the fault code to the FIM (Fault Isolation Manual, or equivalent) which further isolates the fault. At this point, if the exact cause of the fault is not known, the maintenance personnel are given a general idea of what the cause(s) of the problem is and what maintenance action(s) will be required when the airplane arrives, thereby tending to minimize the possibility of a delayed or grounded flight.

BSPR:
The FRM is bulky and difficult to use. EX: Present FRMs are somewhat large and total approximately 600 81/2.times.11 inch pages. The book is divided by Airline Transport Association (ATA) chapter. Each chapter contains a pictorial contents, an alphabetic contents, and the fault code diagrams (which make up approximately 4/5 of the manual). The fault code diagrams (logic trees) contain an average of 5 to 10 fault codes each. There are roughly 2500 fault codes in each airplane copy. On short flights a flight crew may wait until the flight has landed and is taxiing to the terminal before using the FRM. This creates two problems: viz. (1) The crew may not have seen or remembered all conditions, actions, and indications when the fault occurred, thus creating an unreliable fault code; and (2) the fault codes are designed to be radioed in the air in order to allow the maintenance personnel time for part procurement, planning, etc. If the fault is of an intermittent type, a future failure may be indicated. If the fault is too quickly gone, the flight crew will likely not see all indications, if any at all.

BSPR:
(d) a "send data" discrete signal is awaited from the aircraft's onboard FMC (Flight Management Computer);

BSPR:
(e) on command, a "data present " discrete signal is sent to the aircraft's onboard ARINC Communications Addressing and Reporting System (ACARS) and a "transmission available" discrete signal is awaited;

DRPR:
FIG. 3 is a system block diagram showing aircraft installation of the present AFRS wherein the Phase I, Phase II, and Phase III aspects of the installation are detailed to facilitate an understanding of system operation and also how the present system concept may be adapted in steps, and wherein these modifications are shown in dotted line representation;

DEPR:
ACARS: (ARINC Communications Addressing and Reporting System) System presently installed on many airplanes at operator's option. Used for two-way digital communications from airplane to ground station via ARINC communications network.

DEPR:
ARINC: (Aeronautical Radio Inc.) North American organization which, among other services, provides a ground-based digital air/ground communications network for subscribing airplane operators and standards for airplane design.

DEPR:
BITE: (Built In Test Equipment) Monitoring circuits, on a system level, which periodically check the operation of that system. In the event of a failure, a signal is sent to display a flag and/or store the fault in that system's or another system's memory for maintenance referral.

DEPR:
FIM: (Fault Isolation Manual) Aircraft manufacturing company, e.g. Boeing Airplane Company prepared manual presently used by operator's ground personnel on airplanes. The manual is used to decode the fault codes transmitted by the flight crews and to determine the corrective maintenance actions required when the airplane arrives.

DEPR:
AFRS: (Automatic Fault Reporting System) System of fault reporting which also replace presently used FRM type manuals and portions of presently used FIM type manuals.

DEPR:
SITA: (Societie Internationale de Telecommunications Aeronautiques) European equivalent of ARINC which will soon provide a worldwide ground-based digital air/ground communication network for subscribing airplane operators.

DEPR:
DFDAU: (Digital Flight Data Acquisition Unit) System used to acquire real time airplane data, format it per airline requests, and provide selectable output to the flight recorders.

DEPR:
ADC: (Air Data Computer) Senses environmental conditions around the airplane (i.e. airspeed, altitude, etc.) from data provided by pilot static system.

DEPR:
IRS: (Inertial Reference System) System which senses airplane movement and is used to calculate altitude, position, speed, etc. for navigation purposes.

DEPR:
DME: (Distance Measuring Equipment) Provides radio distance from airplane to ground-based DME stations.

DEPR:
ILS: (Instrument Landing System) Radio navigation aid system used to guide airplane to runaway during landings.

DEPR:
RA: (Radio Altimeter) Provides radio distance from airplane to ground.

DEPR:
WXR: (Weather Radar) Provides pictorial presentation of weather patterns ahead of the airplane.

DEPR:
PSEU: (Proximity Switch Electronics Unit) Monitors airplane proximity switch logic.

DEPR:
BPCU: (Bus Power Control Unit) Controls aircraft electrical power distribution.

DEPR:
MCDP: (Maintenance Control Display Panel) System used to isolate and display autopilot faults on ground only.

DEPR:

The Phase II and III Automatic Fault Reporting System (AFRS) (FIG. 1) is an all solid-state rack mounted unit that monitors and compares the data outputs of various airplane systems (depending on phase). The AFRS provides fault outputs when data presence, validity, or tolerance errors are detected.

DEPR:
The AFRS provides automatic comparing/monitoring of various aircraft data parameters during flight, and supplies fault outputs when failures are detected to the ACARS for transmission to ground-base maintenance operations. This AFRS system is one to be installed on airplanes and used in conjunction with presently installed airplane systems with the objective of reporting airplane system fault conditions prior to landing. The system would be completely automatic, thus relieving the flight crew from the responsibility of isolating and reporting BITE detectable fault conditions during flight. In addition, the information received by ground maintenance personnel will be much more exact, allowing more time for parts acquisition and the scheduling of maintenance personnel. Depending on how the information is used on the ground and the individual capabilities of each airline, this information can be fed into their main computer and used to assist in inventory control, airplane scheduling, flight crew scheduling, passenger scheduling, periodic maintenance scheduling, etc. The primary objective of the present AFRS system, however, is that of automatic airplane fault reporting. The functional responsibilities of the system are as follows (See FIG. 1):

DEPR:
The unit consists of an aluminum chassis with attached front panel and top plate, removable circuit cards, and a one-piece dust cover. The front panel contains a swing-out handle for ease of installation/removal, and two push-button switches (SELF TEST and DATA DUMP) located on the upper portion of the panel, as seen in FIG. 2. Cooling air inlet holes are located on the bottom of the unit with outlet holes located on the top of the unit. The importance of this system is the automatic reporting of presently available on-airplane fault information to the individual airline by using presently installed systems for the detection of faults and the unique transmission of the fault data. The unique control and processing of the data on the airplane will require a new box (i.e. ARFS) (10).

DEPR:
The Phase II and III AFRS monitors and compares the ARINC 429 low-speed outputs of various airplane systems (depending on phase--see FIG. 3). The AFRS provides outputs for transmission by ACARS whenever a difference between monitored system outputs exceed a predetermined value, and/or a warning flag condition is detected.

DEPR:
The internal circuits monitor and compare the low-speed ARINC 429 outputs of the applicable airplane systems based on discrete inputs. The monitoring and comparison functions result in the transmission to ACARS of parameter warnings via discrete and serial outputs.

DEPR:
The Phase II and III AFRS monitor and compares outputs from various aircraft electronic units. Failure outputs are provided to the ACARS whenever faults or excessive differences are detected between monitored inputs.

DEPR:
Due to the potential change impact on present airplane installations, the system can be installed in three phases (Phases I, II, and III). The first phase will only be software changes to the MCDP and two new ARINC data buses (25) between the MCDP (22) and the ACARS (13). This will be used to prove the concept and will provide all autopilot (FCC (17), FMC (12), TMC (9)) fault data to the ground via ACARS (13) and ARINC/SITA (10). The second phase will require the new AFRS box (10) (hardware) which will basically be a data management computer. This will also require new wiring (20) from the DFDAU (9) inputs (21) and reprogramming of some of the inputting systems. Phase II will provide fault data from a majority of the Navigation and Warning Systems (2). Phase III will include the fault data from every system on the airplane (23). This phase is presently considered as a future evolvement of the system due to extensive wiring (24) and software changes which will be required to presently installed system. The AFRS (10), however, will be designed to accommodate this future expansion capability. In conclusion, for present airplanes (i.e. 757/767), the present plan is to proceed through

Phase II in order to provide the greatest amount of fault data while requiring the least amount of change to the airplane.

DEPR:
Digital inputs to the AFRS are received from the system listed in Table II (by phase) via ARINC 429 low-speed data buses. Also, analog and discrete inputs are received via standard airplane wiring. Each phase will include the information received by the previous phase(s). The digital inputs are monitored for signal presence and validity. Input discretes from various equipment are received via program pin selections in the aircraft wiring. Failure outputs are provided if data inputs are not present, not valid, or excessive differences are detected between monitored inputs.

DEPR:
The power supply converts the 115 V AC, 400 Hz aircraft power to +5, +5 KA, +12, and -12 V DC power required for AFRS operation. The +5 KA is a keep-alive voltage applied to the RAM to maintain memory during power switching or transients. The +5, +12, and -12 V outputs are short circuit protected by regulator/limiter/shutdown circuits. Monitor circuits will inhibit the AFRS and cause an AFRS fault warn output if the power supply voltages are not correct.

DEPR:
Note: Due to system and system output redundancy, cross channel checks are used to isolate faults between wiring or box problems. Also, due to redundancy and the vast number of systems and wiring, it is impossible to illustrate the entire airplane's systems.

DEPR:
g. On the ground, the operator will use this information to aid his maintenance scheduling, parts acquisition, and control flight crew and passenger rescheduling (if required) and any other application desired to reduce airplane turnaround time.

DEPV:
(7) When the FMC commands AFRS to send data, the AFRS will poll ACARS for transmission time. If the line is not busy, ACARS will transmit the data to an ARINC/SITA ground station via the airplane's VHF communications system. ARINC/SITA, in turn, will transmit the data to the correct operator via land lines.

CLPV:
an aircraft communication addressing and reporting system for providing a signal representative of a ready condition and a discrete signal representative of a transmission complete and received condition;

CLPV:
a transient logic circuit responsive to said fault code information and said signal representative of a ready condition of an aircraft communications addressing and reporting system for receiving said fault code information;

CLPV:
said transient logic circuit dumping said fault code information for transmission through said aircraft communications addressing and reporting system in response to the presence of said signal representative of a ready condition of said aircraft communications addressing and reporting system, and further repeating said dumping of said fault code information for transmission through said aircraft communications addressing and reporting system until receiving said discrete signal representative of said transmission complete and received condition from said aircraft communications addressing and reporting system.

ORPL:
Batten, "The Use of Computer Testing", Aircraft Engineering, vol. 47, No. 6 (1975).